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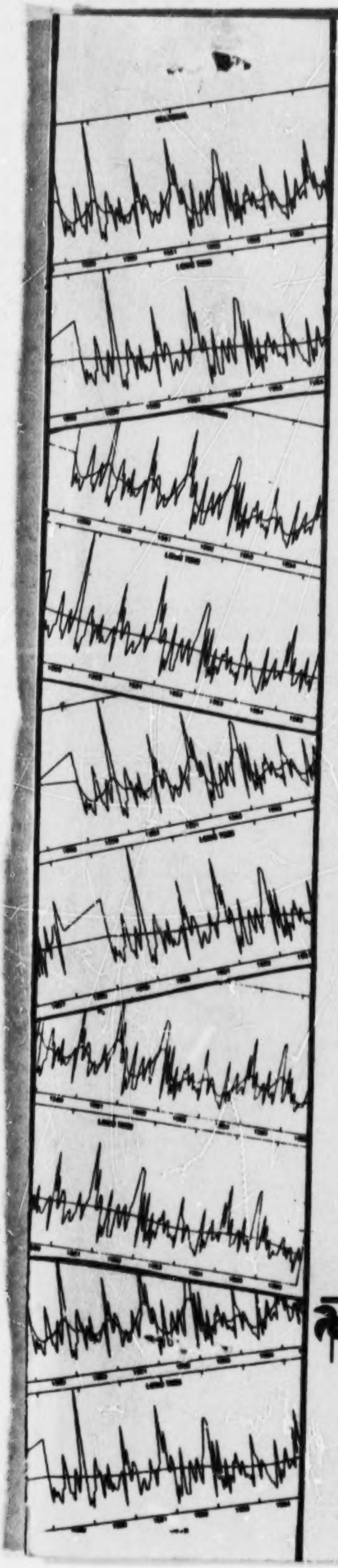

CHARACTERISTICS
OF
PARTICULATE PATTERNS

1957–1966

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Environmental Health Service

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ERRATA

AP-61 - CHARACTERISTICS OF PARTICULATE PATTERNS, 1957-1966

Please make the following changes in your copy(s) of subject report.

Page 12, paragraph 1, line 9, the next to last sentence should read:

> "Sites demonstrating atypical seasonal patterns were classified as unusual."

Page 80:

The graph for Cheyenne, Wyoming, belongs in the Urban section.

Page 101, reference 1:

PSH should be PHS.

CHARACTERISTICS
OF
PARTICULATE PATTERNS
1957–1966

by
Robert Spirtas
and
Howard J. Levin

Division of Air Quality and Emission Data

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Environmental Health Service
National Air Pollution Control Administration
Raleigh, North Carolina
March 1970

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National Air Pollution Control Administration Publication No. AP-61

ABSTRACT

The National Air Surveillance Networks (NASN) have collected samples of suspended particulate matter since 1957. The resulting suspended particulate data are graphically summarized by the application of Whittaker-Henderson Type A curve-smoothing formulas to 10 years of data. Data from 60 urban stations and 20 nonurban stations were studied by this technique, which brings out the underlying cyclical patterns and long-term trends in nationwide levels of suspended particulate matter. Seasonal patterns are evident for many urban and nonurban stations, and the seasonal characteristics of the two types of stations contrast sharply. Long-term trends are downward at many center-city urban sites, but are upward at some nonurban sites.

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CHARACTERISTICS OF PARTICULATE PATTERNS 1957 – 1966

INTRODUCTION

The National Air Surveillance Networks (NASN) have been collecting samples of suspended particulate matter since 1957. Review and careful evaluation of the substantial amount of data accumulated in the first 10 years of Network operation is now appropriate. Previous analyses have generally been limited to comparisons of means and variances, or to application of other conventional statistical techniques. This publication presents a time-series approach to the study of the data; it considers particulate levels as a dynamic series of events occurring over a 10-year interval. This approach brings out some of the more subtle characteristics of the data. There were more than 350 sites for which at least 1 year's data had been collected during the period 1957 through 1966. From this resource, 60 urban and 20 nonurban sites were selected for analysis on an individual basis because of their continuity of data over the 10-year period.

The data are graphically summarized by the application of Whittaker-Henderson Type A curve-smoothing formulas, because the derived curves provide a visual perspective of seasonal patterns and long-term trends and offer insights into the nationwide behavior of the concentrations of suspended particulate matter. Other techniques are available for analyzing these data, but mathematical smoothing summarizes masses of data most comprehensibly (Figure 1). In addition to mathematical smoothing, standard statistical techniques have been used to categorize the 80 sampling sites with respect to seasonal patterns and long-term trends.

Suspended particles are a conspicuous class of air contaminant because they are largely responsible for the most visible consequences of air pollution — the dirt, the grime, and the soiling of materials. The subtle health effects of particulate matter, however, are more ominous. Some particles contain biologically active substances, such as benzo-a-pyrene, which may be carcinogenic.[1] Particles also absorb and adsorb harmful gases such as sulfur dioxide and can carry these gases deep into the lungs. Other particles may act as catalysts for chemical reactions in the atmosphere that produce harmful substances. Various systems of the human body may be impaired by particles. The suspected impact of suspended particles on health and environment necessitates an understanding of particulate levels and their trends.

Objectives of the NASN include determination of the nature and extent of air pollution and the study of trends in the levels of various atmospheric contaminants. To accomplish these goals, a standardized sampling technique for measuring suspended particles in the air was developed. Suspended particulate samples are collected by a high-volume sampler, which draws air through an 8- by 10-inch glass-fiber filter. This instrument can extract 99.9 percent of all particles 0.3 micron or greater in diameter.[2] Generally, air flows through the filters at an average rate of 1.4 to 1.7 cubic meters per minute. The accumulated matter on the filter retards the flow of air; consequently, flow rates are sometimes lower at sites with high particulate concentrations.

Under the current NASN procedures, samplers are operated for 1 randomly selected day during each 2-week sampling period. Although this procedure should produce 26 valid samples each year at each site, equipment breakdowns, damaged filters, or skipped sampling periods often limit the number of samples at a site. Those filters that survive quality control intact undergo extensive laboratory analyses, and the resulting data are statistically compiled.

The National Air Pollution Control Administration already has published many of these data. The 1963 summary of NASN data on suspended particles[3] discusses a nationwide downward trend for the period 1957 through 1963 which becomes apparent in a comparison of annual geometric mean concentrations of suspended particles at center-city urban stations. A subsequent publication, "The Trend of Suspended Particulates in Urban Air, 1957-1964,"[4] primarily concerns the marked decrease in suspended particulate levels at selected sites in 1961. It establishes the statistical significance of the decrease and concisely summarizes possible explanations for the short-term changes.

The present study encompasses the data collected over the 10-year period from 1957 through 1966 for selected urban and nonurban sites. Urban sites are located in the downtown, center-city area. All downtown stations, however, are not equivalent. They are not uniformly situated, and they are characterized by environmental peculiarities. Nonurban stations are positioned in supposedly rural areas. Hence the nonurban category includes a wide diversity of site locations, such as proximate, intermediate, and remote.[5] Because of the differences among sampling sites, care should be used in drawing conclusions from comparisons of such data. The inclusion of a large number of sites in this study, however, permits generalizations about typical urban and nonurban characteristics.

DEVELOPMENT AND APPLICATION OF THE METHOD

The development of a technique for summarizing the 10 years of data accumulated at each sampling site was an initial concern in this study. At first, raw data values were plotted on graphs, and the adjacent raw data points were connected by straight lines. Wide fluctuations in the data, however, prevented any substantive detection of site characteristics. A curve-smoothing technique was finally employed to transform the irregular spiked graphs to curves which could be more readily interpreted and which emphasized the patterns and trends in the raw data graphs.

On the average, 250 samples have been collected at each of the 80 selected sites. Since it had been determined that the resulting data can be best interpreted if converted to a more comprehensible form such as smoothed curves, this conversion required certain assumptions. This section explains briefly the methods and assumptions used in converting the data.

At the outset, criteria for data subjected to analysis were necessary. For a year's data to be adequate, a minimum number of samples must be collected in several time periods, distributed evenly throughout the year.[6] A year for which adequate data are available is designated a "valid year"; others are referred to as "invalid years."

The selection of sites included in the study was based upon a criterion of 7 or more valid years of NASN data from 1957 through 1966. Kent County, Delaware, for which only 6 years of valid data are available, is the only deviation from the criterion. This nonurban site was included to provide a picture of nonurban particulate concentration in the proximity of the densely populated eastern seaboard. No nonurban site had a valid year in 1957, because of the priority given to the establishment of urban sites in the reorganization and development of the current NASN.

This study provides in condensed, graphic form all the valid data for each of 80 sites from 1957 through 1966. Particulate levels have been plotted for each sampling period, and graphs have been constructed by connecting the points consecutively (Figures 2-81). Two graphs have been prepared for each site. The top graph in each figure presents the raw data curve and a superimposed smoothed curve approximately representative of seasonal patterns. The lower graph depicts the same raw data curve and a superimposed curve illustrating long-term trends. The analyses of particulate levels and their characteristics are based on both the raw data and the smoothed curves.

In order to conserve space, the very few raw data values exceeding 500 $\mu g/m^3$ were plotted as 500 $\mu g/m^3$ in the graphical routine. Actual values were used, however, in calculations and in construction of the smoothing curves.

The number of valid samples within a valid year ranged between 20 and 26. Since samples had been collected on random days within the sampling periods, pinpointing the exact day of sampling was impractical on a small-scale graph.

Consequently, the raw data points within that year were graphically equispaced throughout the year.

Invalid years required special attention. The computer was programmed to estimate raw data values for invalid years to provide expediency in the graphical routine and to aid in detection of characteristic patterns. The expected particulate level for an invalid year was estimated and plotted as the level for the first sample during that year. The graphs were completed by drawing connecting lines from this estimate to the last sample value in the preceding valid year and to the first sample value in the next valid year. This estimate had little effect on calculations; any reasonable estimate would have been satisfactory. This estimate, however, should correspond to expected particulate levels.

A time-series analysis emphasizes the trends and patterns of the data. In this approach, the site samplings are viewed as a sequence of events rather than merely a mass of data. The continuity of smoothed curves allows a realistic estimate of what particulate-pollution levels would be if sampled continuously rather than once every 2 weeks. These curves also facilitate a comparison of trends in particulate concentrations at a number of sites, which is more meaningful than a comparison of yearly averages.

The smoothed curves, illustrating the seasonal and long-term characteristics of particulate levels, were constructed for all sampling sites included in the study and were easily adaptable to those sites with invalid data. The flexibility of this method permitted the inclusion of a large number of sites; thus, certain general conclusions could be drawn. Another advantage of smoothing curves is that an opportunity for visual analysis of the characteristics of particulate patterns throughout the 10-year period is afforded.

The mathematical concept of curve-smoothing is not an elementary one, but the visual results can be demonstrated easily. Intuitive methods of drawing a smooth curve through raw data points, such as the use of a French curve, are subjective and produce varying results. In contrast, mathematical techniques are objective, treating all data on the same basis. Since curve smoothing is an innovation in analysis of air pollution data, a description of the process is given.

The formulas used in this study were developed in the field of actuarial mathematics, where curve smoothing is referred to as graduation. Graduation is the process of securing a smooth series which adequately represents basic characteristics from an irregular series of raw data values.

The appropriateness of any graduation depends upon a balance between two interdependent criteria: (1) Smoothness, and (2) fit, or consistency with raw data values. For ultimate smoothness, a straight line approximates all data values; for ultimate fit, raw data values are not graduated at all. Generally, an increase in the smoothness of a curve is accompanied by a reduction in the fit, and vice versa. Since no graduation can provide simultaneously both the best possible fit and the best possible smoothness, a compromise must be reached. Thus, the best graduation is the one that provides the best combination of these two characteristics for the purpose at hand. Applied to the NASN suspended particulate data, an emphasis on smoothness produces the long-term trend curves in the lower graph in each figure, whereas more emphasis on fit produces the seasonal-pattern curves in the upper graph in each figure.

A number of different graduation methods are available, ranging from simple graphic methods to complicated mathematical techniques. The choice of any one method depends on the extent and form of the raw data, the purpose for which the graduation is used, the relative emphasis to be given each of the qualities, and the graduator's technical familiarity with the data and the technique. The Whittaker-Henderson Type A Difference Equation Method used in this analysis is formulated as the minimization of an expression combining weighted measurements of fit and smoothness.

The Whittaker-Henderson formula is essentially a finite-difference function permitting variation of the blend between fit and smoothness by variation of the parameter 'a', a positive number fixing the relative weight of these qualities. Small values of 'a' emphasize fit, whereas large values emphasize smoothness. Since a detailed understanding of the method requires a knowledge of numerical analysis and finite differences, and since the formula and its derivation are not necessary for interpreting the graphs, further details are omitted here.*

The graphs in Figure 1 demonstrate the graduation effects of different values of this parameter. The value a=3 is used in plotting seasonal patterns because the graduated curve retains fluctuations characteristic of monthly variations yet eliminates random undulations resulting from individual measurements. Since the long-term curves require emphasis on general tendencies over the 10-year period rather than short-term patterns in the raw data, the value a=20 is used in plotting long-term curves.

Although the mathematical derivation of the Whittaker-Henderson method is complicated, the graphs produced with this method are straightforward illustrations of patterns and trends in particulate pollution.

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*A mathematical development of the Whittaker-Henderson Type A Formula may be found in references 7 and 8. This derivation is summarized in reference 9.

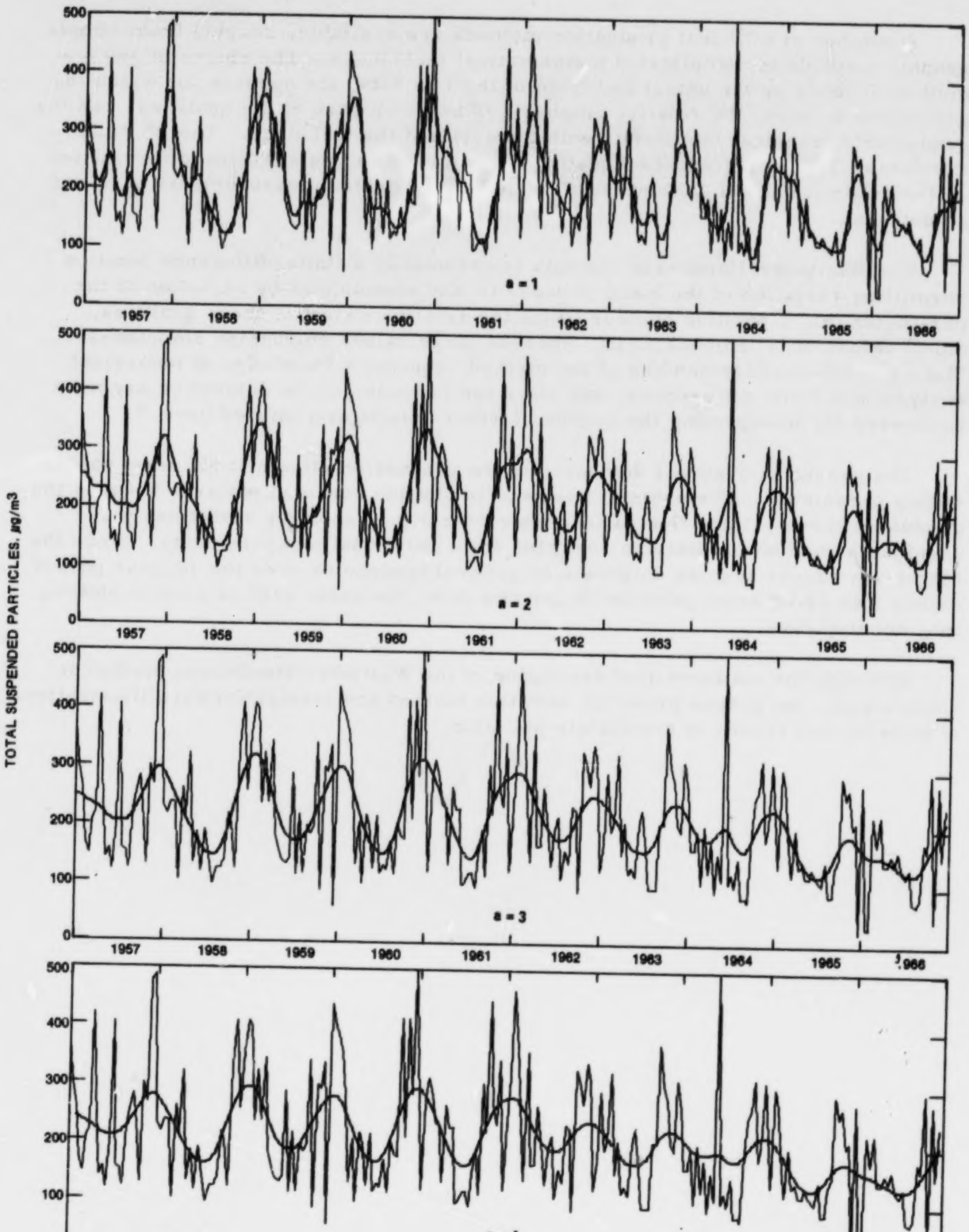

Figure 1. Variations in curves for selected values of graduation parameter.

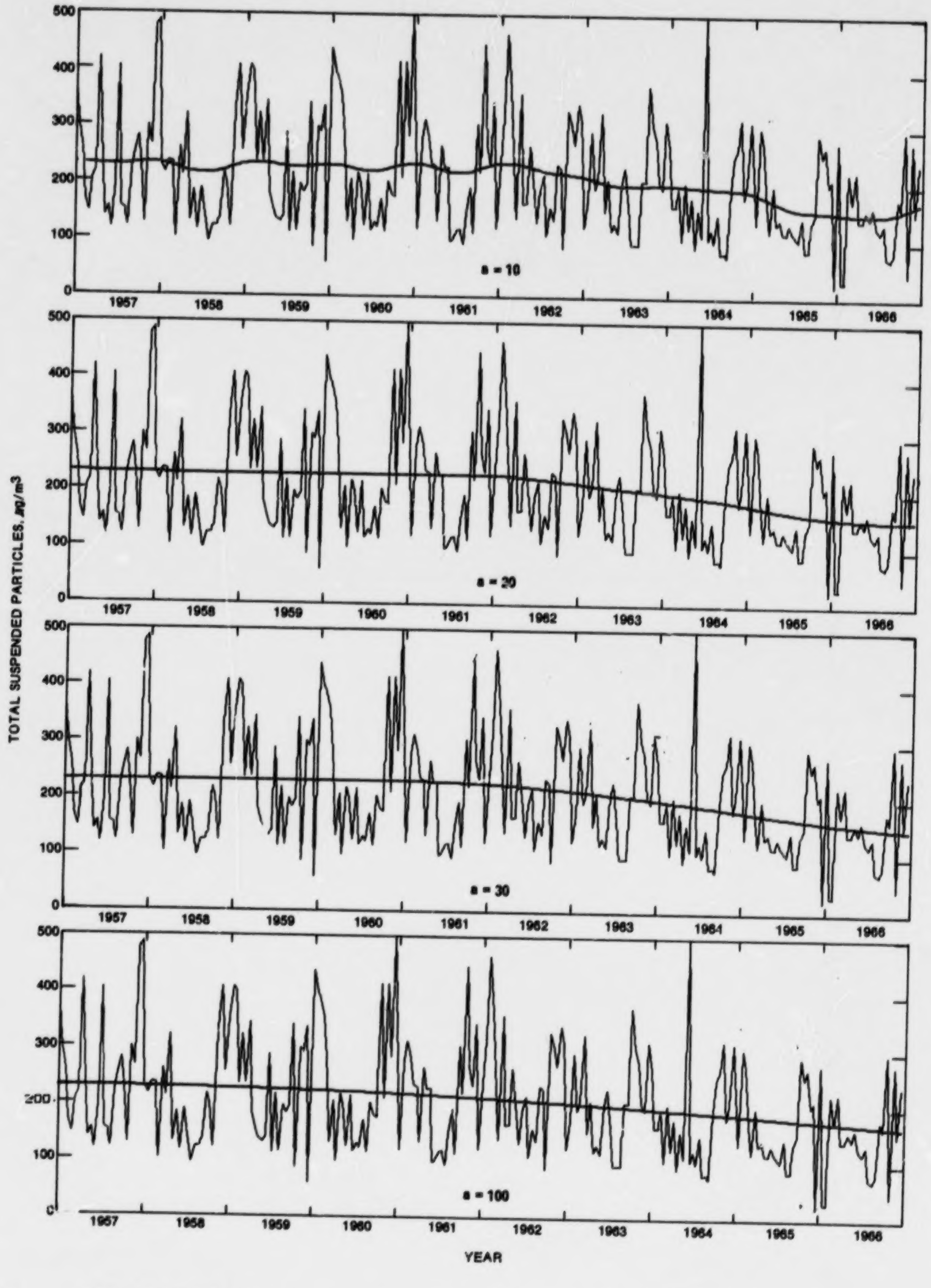

Figure 1 (continued). Variations in curves for selected values of graduation parameter.

DISCUSSION

The smoothed curves presented here adequately illustrate patterns and trends in the data. The reader should thoroughly examine the graphs for sites of specific interest to him. A detailed analysis of all graphs is precluded in this discussion by the lack of sufficient knowledge of local environment and meteorology and by the large number of the graphs. Rather than attempt a detailed scrutiny of each graph, the sites have been categorized according to some of the prominent features of the graphs.

Individual graphs were used, however, to follow up the previously mentioned 1961 drop study.[4] Seasonal patterns of the urban sites included in that study showed that particulate concentrations during the 1961-62 winter were, in general, quite low. In contrast, the particulate concentrations at many urban sites during the 1960-61 winter were relatively high. This additional information may redefine the 1961 drop in annual mean concentrations as the result of a drop in winter particulate concentrations.

Study results are partially summarized in Tables 1 and 2, which categorize center-city urban and nonurban sites according to their seasonal patterns and long-term trends. These tables also present for each site the geometric means and the geometric standard deviations for the two consecutive 5-year periods since 1957. The different characteristics of each individual site in these tables should be considered together. For example, the mean particulate concentrations must not be ignored in a discussion of trends, because the two are interrelated. The seriousness of the particulate problem depends ultimately on concentration levels. Thus, long term changes may be more significant for a site with high mean concentrations than for a site with consistently low levels. Frequent reference to the graphs will illustrate the results presented in these tables.

The geometric standard deviations can provide important information about the sampling sites. Large geometric standard deviations can indicate, for example, an irregular distribution of particulate sources. Sources may be scattered in such a way that particulate levels are strongly dependent on wind direction. If major sources of particulate pollution are concentrated in one area of the city, winds from that direction may produce high particulate levels while winds from other directions are likely to result in low levels. The final effect of such a situation is a wide deviation in particulate concentrations, such as that observed in Charleston, West Virginia, where wide deviations are due primarily to changes in wind direction and wind velocity.

In addition, the combination of a small geometric standard deviation and a high mean concentration may be due to distribution. Such a combination may result if the sources of pollution are distributed about the sampling site in such a way that wind direction has little effect on particulate concentrations. Frequent high levels can result also if the sampling site is in line with the prevailing wind direction from the sources.

Table 1. CENTER-CITY URBAN CHARACTERISTICS OF SUSPENDED PARTICLES

Site	1957-1961		1962-1966		Long-term trend	Change in geometric standard deviation	Seasonal pattern[a]
	Geom. mean, μg/m^3	Geom. std. dev., μg/m^3	Geom. mean, μg/m^3	Geom. std. dev., μg/m^3			
Birmingham, Ala.	125.6	1.85	124.5	1.68	No change	Down[b]	Urban
Anchorage, Alaska	83.4	2.27	65.9	2.31	Down[b]	No change	Nonurban
Phoenix, Ariz.	206.5	1.58	165.7	1.73	Down[c]	No change	Urban
Little Rock, Ark.	74.1	1.63	87.0	1.74	Up[b]	Up[c]	None
Los Angeles, Calif.	164.2	1.56	124.5	1.60	Down[c]	No change	Urban
San Diego, Calif.	85.4	1.54	76.3	1.53	Down[b]	No change	Urban
San Francisco, Calif.	65.3	1.69	60.0	1.60	No change	No change	Urban
Denver, Colo.	137.4	1.64	125.1	1.54	No change	No change	Urban
Hartford, Conn.	88.8	1.59	95.6	1.58	No change	No change	Possible urban
New Haven, Conn.	84.8	1.47	91.9	1.52	No change	No change	Unusual
Wilmington, Del.	175.3	1.64	131.1	1.41	Down[c]	Down[c]	Urban
Washington, D. C.	106.8	1.56	87.2	1.45	Down[c]	Down[b]	None
Tampa, Fla.	85.9	1.39	84.1	1.44	No change	No change	None
Atlanta, Ga.	99.4	1.56	93.4	1.49	No change	No change	None
Honolulu, Hawaii	48.8	1.50	38.7	1.37	Down[c]	No change	Urban
Boise, Ida.	104.7	1.53	80.3	1.53	Down[c]	No change	Urban
Chicago, Ill.	179.4	1.39	130.4	1.47	Down[c]	Up[b]	None
East Chicago, Ind.	176.7	1.70	183.7	1.51	No change	Down[b]	None
Indianapolis, Ind.	157.1	1.35	148.8	1.41	No change	No change	None
Des Moines, Iowa	150.2	1.56	116.8	1.58	Down[c]	No change	Unusual
Wichita, Kan.	86.3	1.59	88.8	1.56	No change	No change	None
New Orleans, La.	88.4	1.37	85.2	1.44	No change	Up[b]	None
Portland, Me.	86.3	1.55	70.7	1.57	Down[c]	No change	None
Baltimore, Md.	131.5	1.51	130.3	1.49	No change	No change	Urban
Boston, Mass.	131.3	1.45	125.3	1.46	No change	No change	Urban
Detroit, Mich.	134.1	1.51	135.3	1.63	No change	Up[b]	None
Minneapolis, Minn.	94.4	1.75	74.8	1.50	Down[c]	Down[c]	None
Jackson, Miss.	71.7	1.60	69.1	1.46	No change	Down[b]	None
Kansas City, Mo.	140.7	1.50	129.3	1.48	No change	No change	Possible urban
St. Louis, Mo.	159.7	1.58	131.1	1.44	Down[c]	Down[c]	None
Helena, Mont.	54.7	2.04	48.7	1.73	No change	Down[c]	Unusual
Omaha, Nebr.	106.1	1.62	107.3	1.49	No change	Down[b]	Unusual
Newark, N. J.	97.2	1.63	103.8	1.54	No change	No change	None
Albuquerque, N. M.	183.5	1.71	114.6	1.70	Down[c]	No change	Possible urban
New York City, N. Y.	167.9	1.48	164.9	1.56	No change	No change	None
Charlotte, N. C.	114.4	1.59	101.3	1.62	Down[b]	No change	Urban
Bismarck, N. D.	80.0	1.77	78.7	1.94	No change	Up[b]	Unusual
Cincinnati, Ohio	124.6	1.45	129.2	1.50	No change	No change	Urban
Cleveland, Ohio	154.5	1.51	119.4	1.53	Down[c]	No change	None
Columbus, Ohio	129.0	1.51	108.1	1.48	Down[c]	No change	Unusual
Dayton, Ohio	113.0	1.49	117.2	1.64	No change	Up[b]	None
Youngstown, Ohio	137.7	1.56	136.1	1.56	No change	No change	Unusual
Portland, Ore.	75.5	1.77	85.7	1.93	No change	Up[b]	Unusual
Philadelphia, Pa.	162.3	1.52	155.5	1.41	No change	Down[b]	None
Pittsburgh, Pa.	160.3	1.73	150.6	1.55	No change	Down[c]	None
Providence, R. I.	100.1	1.54	106.9	1.48	No change	No change	None
Columbia, S. C.	106.8	1.41	73.2	1.50	Down[c]	No change	None
Sioux Falls, S. D.	81.3	1.75	64.6	1.64	Down[c]	Down[b]	None
Chattanooga, Tenn.	190.1	1.55	154.4	1.50	Down[c]	No change	None
Nashville, Tenn.	126.6	1.57	116.3	1.57	No change	No change	Possible urban
Dallas, Tex.	91.4	1.71	91.6	1.56	No change	Down[b]	Possible urban
Houston, Tex.	104.8	1.64	94.3	1.47	Down[b]	Down[c]	None
San Antonio, Tex.	105.9	1.71	72.0	1.52	Down[c]	Down[c]	Urban
Salt Lake City, Utah	105.5	1.64	108.3	1.63	No change	No change	Urban
Burlington, Vt.	50.6	1.53	56.8	1.61	Up[b]	No change	Nonurban
Norfolk, Va.	95.9	1.49	96.7	1.52	No change	No change	None
Seattle, Wash.	79.4	1.62	68.2	1.51	Down[c]	Down[b]	None
Charleston, W. Va.	171.2	2.20	169.0	2.07	No change	No change	Urban
Milwaukee, Wis.	139.4	1.49	120.0	1.63	Down[c]	Up[b]	None
Cheyenne, Wyo.	42.0	1.69	33.7	1.72	Down[c]	No change	Nonurban

[a] Definitions for seasonal patterns can be found in the text.

[b] Statistically significant; categories are explained in the text.

[c] Highly significant statistically; categories are explained in the text.

Table 2. NONURBAN CHARACTERISTICS OF SUSPENDED PARTICLES

Site	1957-1961		1962-1966		Long-term trend	Change in standard geometric deviation	Seasonal pattern[a]
	Geom. mean, μg/m^3	Geom. std. dev., μg/m^3	Geom. mean, μg/m^3	Geom. std. dev., μg/m^3			
Grand Canyon Pk., Ariz.	16.7	2.42	18.5	2.11	No change	Down[b]	Nonurban
Montezuma Co., Colo.	11.3	2.15	12.2	2.60	No change	Up[b]	Nonurban
Kent Co., Del.	58.1	1.44	56.3	1.54	No change	No change	Nonurban
Butte Co., Idaho	18.6	2.08	13.6	1.91	Down[c]	No change	Nonurban
Parke Co., Ind.	54.3	1.43	49.3	1.56	No change	Up[b]	None
Delaware Co., Iowa	36.1	2.02	36.3	1.72	No change	Down[c]	None
Acadia Nat'l Pk., Me.	24.1	1.83	22.3	1.83	No change	No change	Possible nonurban
Calvert Co., Md.	37.6	1.63	39.1	1.46	No change	Down[b]	Possible nonurban
Glacier National Pk., Mont.	11.0	2.63	13.7	2.50	Up[b]	No change	Nonurban
Thomas Co., Nebr.	22.3	1.89	19.4	2.04	No change	No change	Nonurban
White Pine Co., Nev.	10.9	2.61	10.0	2.59	No change	No change	Possible nonurban
Coos Co., N. H.	16.3	1.61	19.6	1.77	Up[b]	Up[b]	None
Cape Hatteras, N. C.	31.5	1.41	48.4	1.81	Up[c]	Up[c]	None
Ward Co., N. D.	20.0	2.22	31.8	2.19	Up[c]	No change	Nonurban
Cherokee Co., Okla.	38.0	1.64	45.4	1.63	Up[b]	No change	None
Clarion Co., Pa.	38.6	1.67	37.1	1.69	No change	No change	None
Washington Co., R. I.	30.2	2.07	37.4	1.99	Up[b]	No change	Nonurban
Richland Co., S. C.	31.0	1.61	32.9	1.56	No change	No change	None
Orange Co., Vt.	38.5	1.43	36.7	1.59	No change	Up[b]	Possible nonurban
Shenandoah Nat'l Pk., Va.	29.8	1.53	30.1	1.59	No change	No change	Nonurban

[a] Definitions for seasonal patterns can be found in the text.

[b] Statistically significant; categories are explained in the text.

[c] Highly significant statistically; categories are explained in the text.

At a number of sites, for example, Cape Hatteras, North Carolina, and San Antonio, Texas, both deviations and mean concentrations changed significantly from one 5-year period to the next. This suggests that the nature of sources has changed. A sustained change in the meteorology is improbable; meteorology in an area is considered to be a random factor and has been accounted for by the smoothing technique. The only factors that can be expected reasonably to change are the emissions and the distribution of sources. Such factors can be affected by installation of controls, opening or closing of plants, and changes in sampler location.

Certain combinations of characteristics at a few sites are puzzling. At Delaware County, Iowa, and at Helena, Montana, the mean changed little while the deviation changed significantly. At the present time, no explanation can be offered for these phenomena.

Although standard statistical measures, such as those discussed above, are useful in this study, data also were analyzed by less conventional methods. The graduated curves themselves yielded much information. For example, the short-term graduated curves were examined for evidence of seasonal patterns over the 10-year period. The criteria for determining seasonal patterns were straightforward but subjective. Typical patterns had to be observed in at least 6 years at urban sites and 5 years at nonurban sites to be considered definite patterns. If a site had only 5 years of typical patterns (4 years for nonurban sites), it was categorized as having a possible seasonal pattern. Sites demonstrating a typical seasonal pattern were classified as unusual. In Tables 1 and 2, all sites are classified as to seasonal patterns on the basis of these criteria.

Typical patterns for urban locations are markedly different from those patterns for nonurban locations. Urban sites generally are characterized by higher levels of particles in the winter than in the summer; nonurban sites, in contrast, generally are characterized by higher levels in the summer than in the winter. A major factor contributing to the higher particulate levels during the winter months at many urban sites is the use of large amounts of fuel for space heating. In these cases, the urban particulate pattern masks the nonurban or background particulate pattern. In those southern cities where gas is burned rather than coal, higher winter concentrations are less prevalent than in coal-burning cities.

A few urban sites were characterized by typical nonurban seasonal patterns. The locations of these sites in remote sections of the country may partially explain this phenomenon. For example, the pattern at Anchorage, Alaska, which would be expected to be influenced by space heating in the winter, resembles the pattern at typical nonurban sampling stations. This situation may be due to the facts that fuel oil is used predominantly for space heating and that construction declines during the winter months. The increased concentrations in the summer months are due largely to the dust raised on the roads and to the resumption of construction.

The relatively high levels at nonurban sites during the summer can be partially attributed to the increases in human activities, such as farming, travel, and vacationing. Also, since summer months are generally drier than other months, more pollen and wind-blown dust (as opposed to man-made pollution) are to be expected during the summer months.

Sites have been classified on the basis of long-term trends, as well as seasonal patterns. To determine these trends, the geometric mean of the first 5-year period, 1957 through 1961, was compared with the geometric mean of the second 5-year period, 1962 through 1966, and the difference was evaluated statistically.* Since no nonurban sites had valid data for 1957, the long-term trend classifications in Table 2 are based on comparisons of the 4-year period 1958 through 1961 to the 5-year period 1962 through 1966.

The five categories established for this classification are:

1. Highly significant downward trend — Statistically significant at the $\alpha = 0.01$ level.

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*Since the suspended particulate data are generally assumed to be log-normally distributed, a two-tailed "t" test was used after a logarithmic transformation had been performed on the original data. Serial correlation should not alter the results of the "t" test significantly.

2. Significant downward trend — Statistically significant at the $\alpha = 0.1$ level.
3. No significant change — Not statistically significant at the $\alpha = 0.1$ level.
4. Significant upward trend — Statistically significant at the $\alpha = 0.1$ level.
5. Highly significant upward trend — Statistically significant at the $\alpha = 0.01$ level.

Table 3 provides the number of urban sites and the number of nonurban sites that fall into each of the five categories listed above. Table 3 shows that particulate levels at many center-city sites decrease over the 10-year interval, despite growth in population and industry. While 25 urban sites, 42 percent of all urban sites, show significant or highly significant decreases in mean levels, only two urban sites exhibit significant increases.

Caution should be taken so that the results presented in Table 3 are not misconstrued. One cannot necessarily infer that the trends in particulate pollution in an entire metropolitan area are represented by data collected at a single center-city site. The reason for this is that for the past ten years there has been substantial growth of population in the suburbs, the construction of industrial parks, the enlargement of traffic arteries, and other major changes that are taking place in our metropolitan areas at some distance from center city points. While we have little substantive data on particulate measurements immediately available from these outlying areas where populations are growing, it is evident that the sources that generate particulate matter are proliferating in these areas.

Table 3. LONG-TERM TRENDS IN SUSPENDED PARTICLES, FREQUENCY TABLE

Long-term trends	Number of center-city urban sites	Number of nonurban sites
Highly significant downward	21	1
Significant downward	4	0
No change	33	13
Significant upward	2	4
Highly significant upward	0	2

The significant decreases at these urban sites should be considered carefully. Of the 21 center-city urban sites characterized by highly significant downward trends, 15 had mean concentrations of more than 100 $\mu g/m^3$ during the 1957 through 1961 period. Thus, most of the sites characterized by highly significant decreases had relatively high particulate levels at the outset of NASN sampling. This decline in pollution levels at center-city sites can be attributed partially to the establishment of control programs in the larger cities with high pollution levels. Significant downward trends also are evident at sites such as Cheyenne, Wyoming; Seattle, Washington; and Sioux Falls, South Dakota; where initial mean concentrations were low. These trends are reflected in the long-term curves as well as in results presented in Tables 1 and 2. For example, the significant decline in particulate levels in Los Angeles, California, is evident in the long-term curve in Figure 6.

No single factor can explain the downward trends of particulate levels at the center-city stations. Urban sprawl must be considered a major factor. Although industry, commerce, and population have continued to grow, much of this expansion has been occurring away from the center-city area. Generally suburban areas are growing at a faster rate than center-city areas, and industry has begun to move to city outskirts. Basic changes in industrial processes and conversion to cleaner fuels for space heating are partially responsible for the decline. Control devices for industry certainly have contributed to the reduction of levels since 1957. In some communities, the lower levels are attributable in part to increased effectiveness of local air pollution control programs. Although the 1963 NASN study suggests that anomalies in meteorological patterns may affect particulate levels, they do not explain these downward trends. As mentioned previously in this discussion, such peculiarities are smoothed out by the graduated curves and have little effect on the graduated values.

Increased traffic density may have caused the rise in particulate levels at some sites. Automobiles and buses are still chief modes of transportation within the center-city. Many of the larger cities, such as Chicago, where particulate levels decline, probably were affected little by increased traffic density in the past 10 years, because their center-city roadways were already saturated by 1957. Demolition and construction associated with urban renewal and expressway projects also may contribute to higher levels at some urban sites.

Many nonurban sites display long-term trends markedly different from those of urban sites. As is shown in Table 3, only 1 of the 20 nonurban sites had a significant decrease in particulate levels, while 13 sites had no significant change. At the remaining six sites, particulate levels increased. Few sizable decreases were expected because the mean levels were very small in 1957. In fact, 30 percent of the nonurban sites had significant increases in particulate concentrations.

Again the movement of industry to city outskirts and to nonurban locations partially explains the rise in particulate levels at those places. The great amount of roadway construction over the past 10 years may have affected particulate levels. Improved and extended highways, especially limited access high speed thoroughfares, have encouraged such widespread traveling in recent years that practically no nonurban site escapes the influence on particulate levels of automobile emissions. An increase due to these emissions should be gradual as the roads are used more and more each year; the graduated long-term curves for many nonurban sites do illustrate such a gradual rise.

If urban sprawl results in a decline in particulate levels at center-city sites, it should produce a corresponding increase in the levels in nonurban areas, thereby causing a shift in the nationwide pollution problem. Increases in construction, commerce, and traffic density associated with urban sprawl may cause the long-term rise in particulate levels. For example, at Cape Hatteras, North Carolina, according to the comparison of 5-year means, a highly significant increase in mean levels has occurred since 1957. This site, with by far the largest increase among nonurban sites, illustrates the effects of many contributing factors. Cape Hatteras followed a typical nonurban pattern until 1963, when an upward trend began. In 1963, home construction near the sampler began to increase rapidly. In the vicinity of the site, more business concerns have been established, and automobile traffic has risen sharply. In addition, a State park was opened nearby.

The situation at Cape Hatteras also illustrates the ambiguities of the classifications "urban" and "nonurban." Cape Hatteras is no longer a truly nonurban site.

As another example, the sampling site in Washington County, Rhode Island, although considered nonurban, is surrounded by the densely populated area of the northeastern seaboard and exhibits some characteristics typical of urban sites. On the other hand, Cheyenne, Wyoming, an urban site, has a lower 10-year geometric mean, 36 $\mu g/m^3$, than many nonurban sites and a clearly nonurban seasonal pattern.

In addition to general characteristics of particulate patterns, in rare instances, the graphs reveal some abnormally high values. For example, when a dust storm swept over the Ward County, North Dakota, site in March of 1963, the station measured a particulate level of 843 $\mu g/m^3$ above the mean for that station over the 10-year period. Anchorage, Alaska, in November of 1958, recorded a level of 487 $\mu g/m^3$. This level, largely due to a volcanic eruption, was 411 $\mu g/m^3$ above the site's 10-year mean. Most of these unusually high spikes are due to stagnations, dust storms, nearby construction, or other unusual conditions.

SUMMARY

The Whittaker-Henderson smoothing curves as applied here are a new approach to the detection of seasonal and long-term patterns in particulate levels. Sites have been classified according to seasonal patterns and long-term trends. This study has established a typical seasonal pattern for urban sites, characterized by high winter levels and low summer levels. In contrast, relatively small geometric means, low winter levels, and high summer levels typify nonurban seasonal patterns. At both urban and nonurban sites, spring and fall appear to be transition periods for particulate levels. Significant decreases in particulate levels were detected for many center-city urban sampling sites. The curves generally reveal a slight increase in particulate concentrations at nonurban sites from 1958 to 1966.

TREND IN TOTAL SUSPENDED PARTICULATES USING WHITTAKER-HENDERSON TYPE A SMOOTHING FORMULAS, 1957-1966

PART I. URBAN SITES

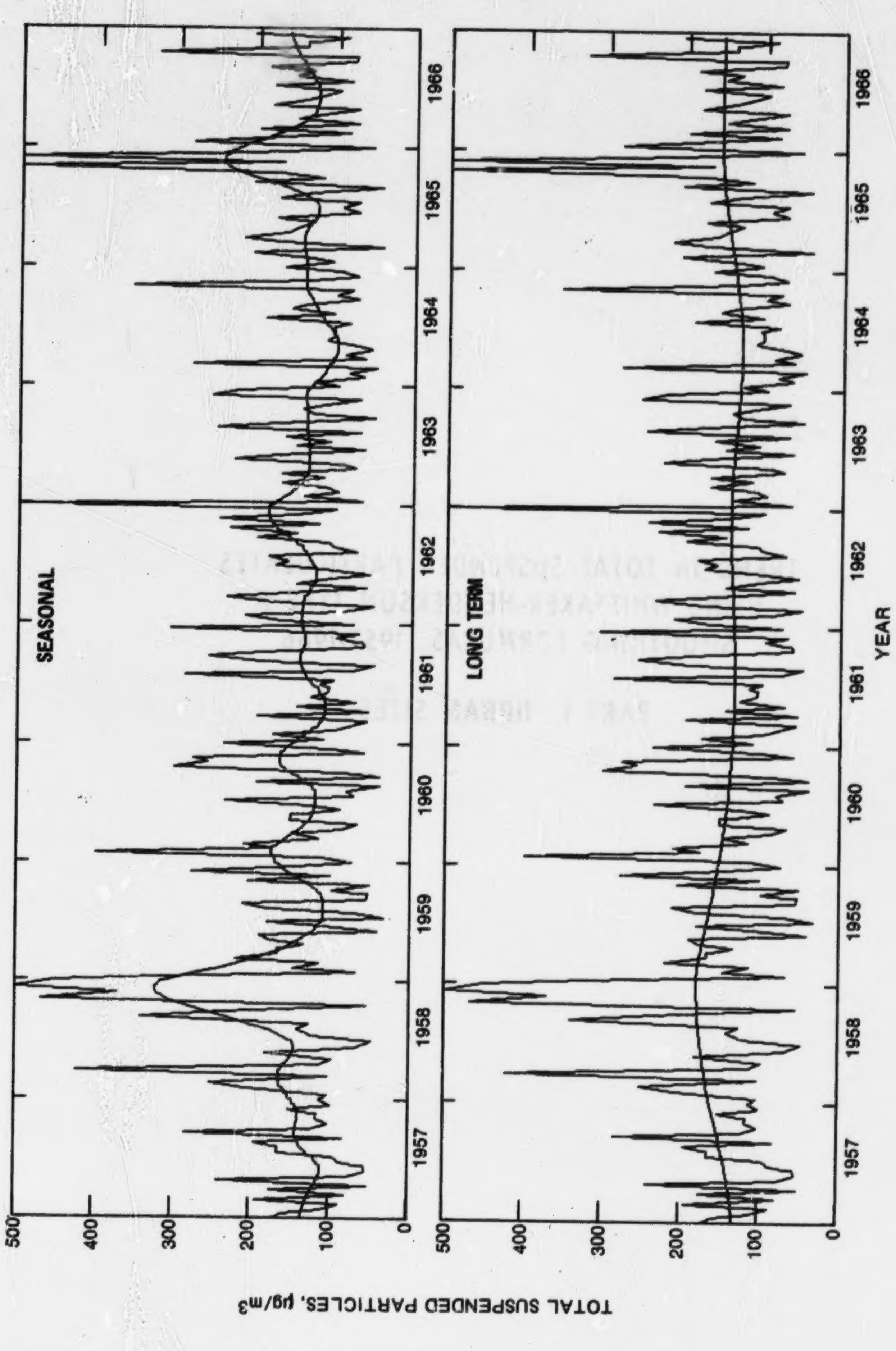


Figure 2. Birmingham, Alabama.

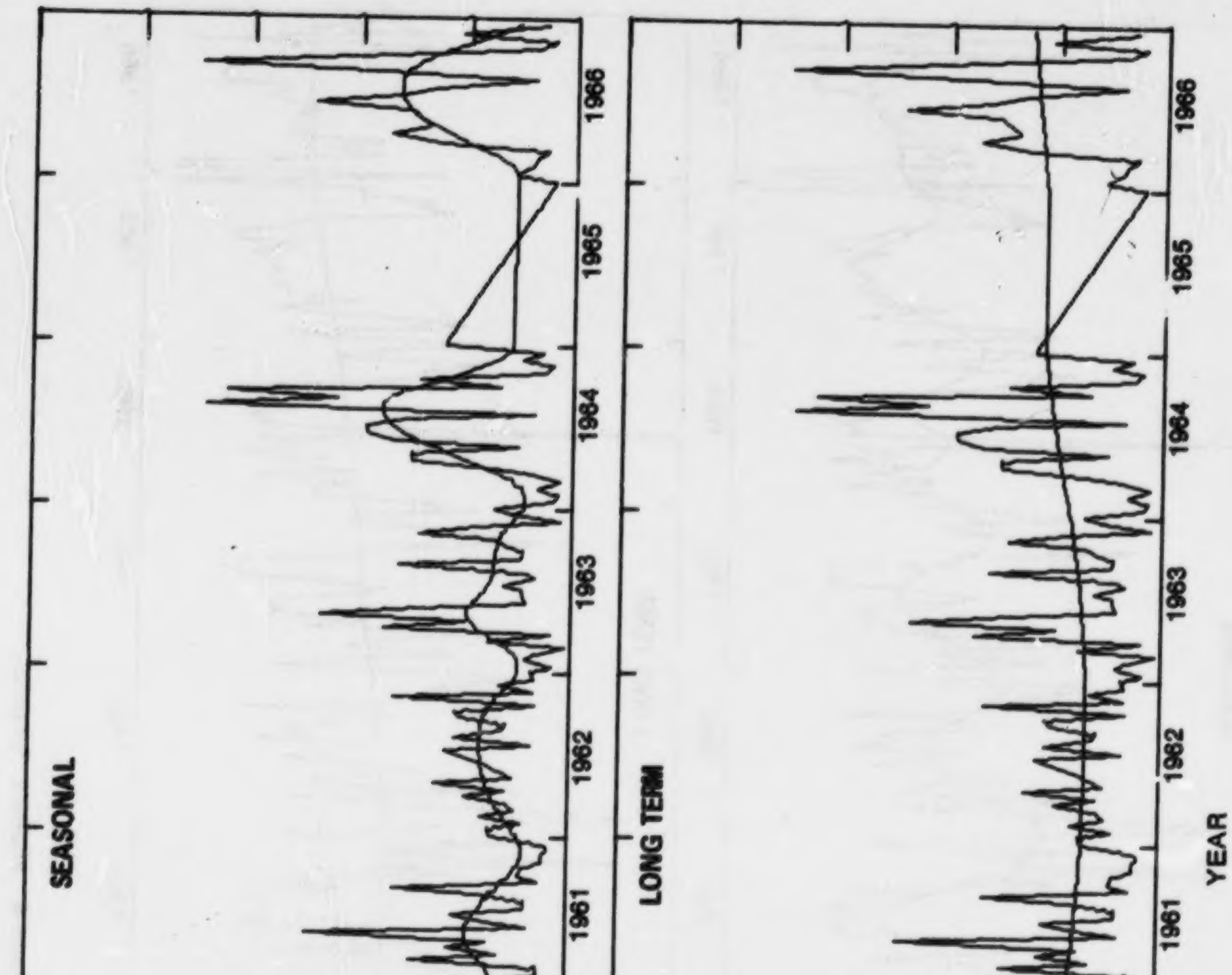


Figure 3. Anchorage, Alaska.

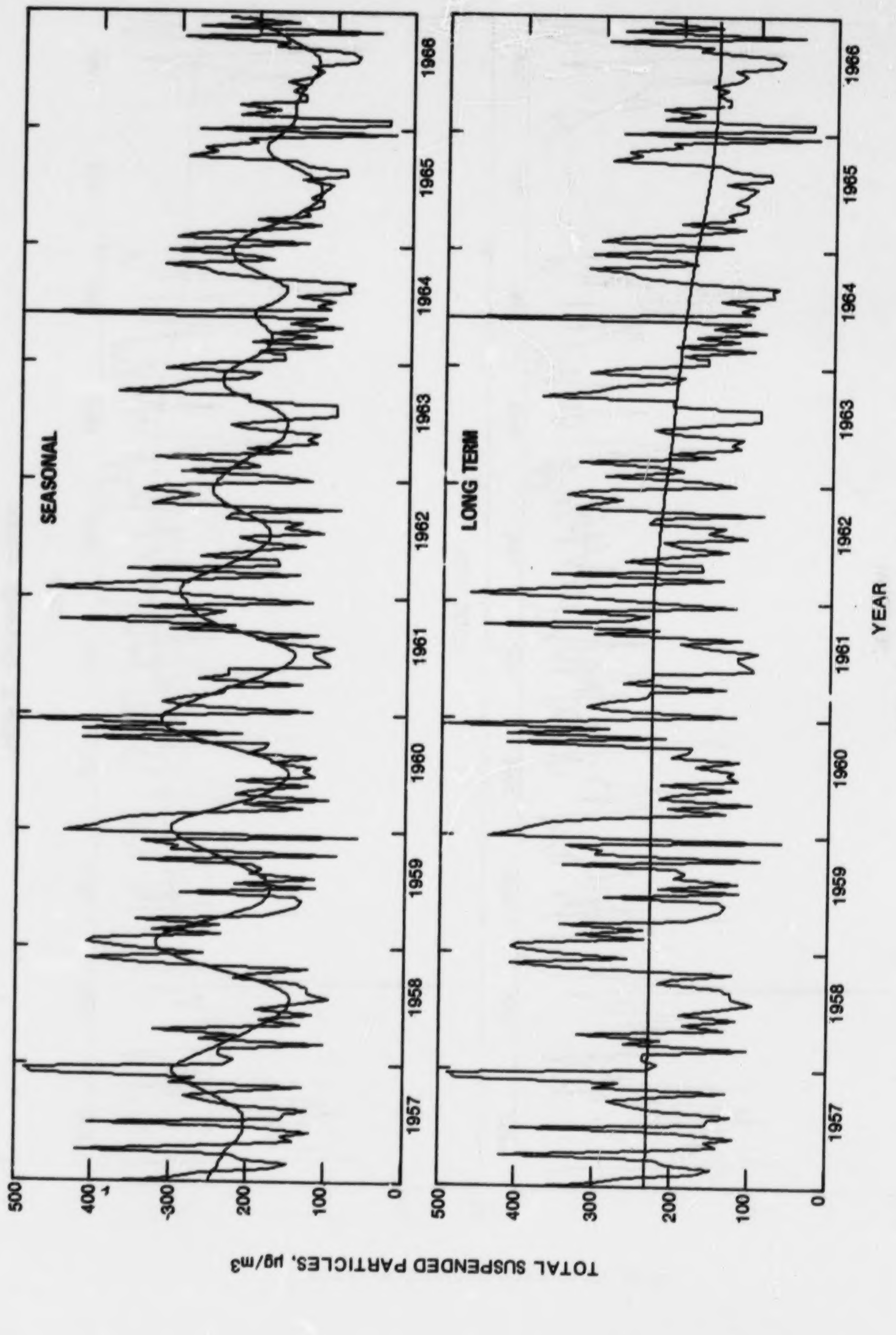


Figure 4. Phoenix, Arizona.

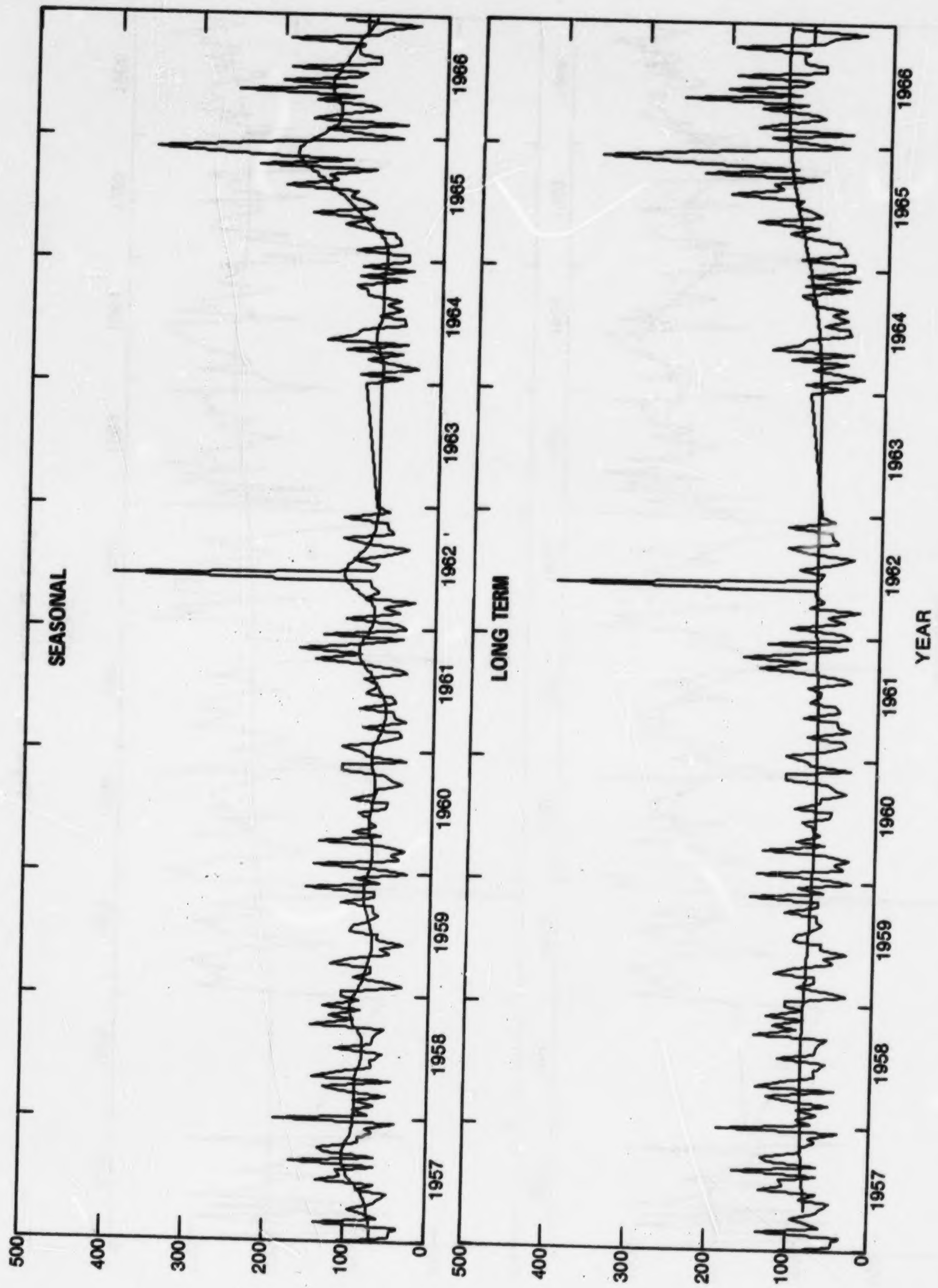


Figure 5. Little Rock, Arkansas.

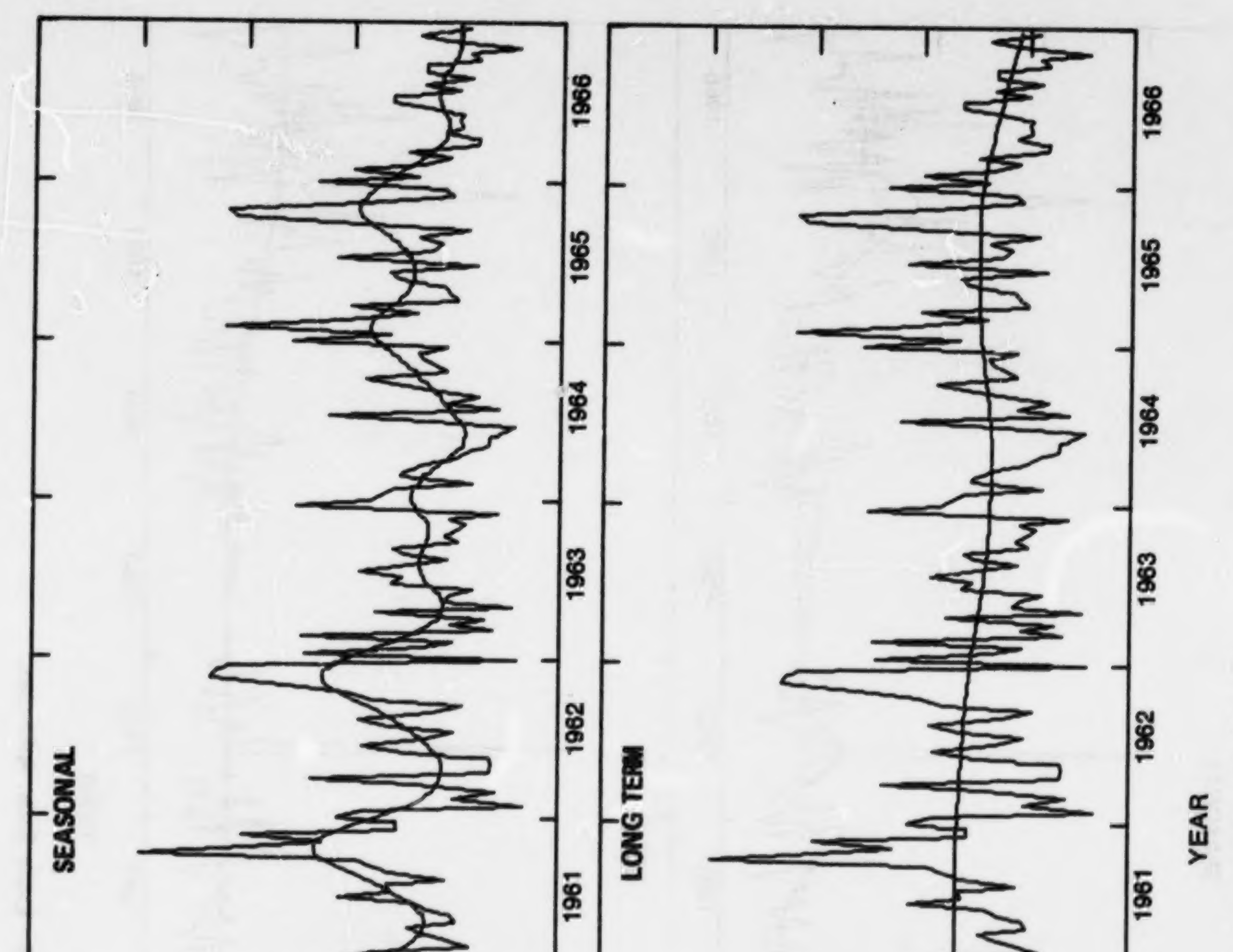


Figure 6. Los Angeles, California.

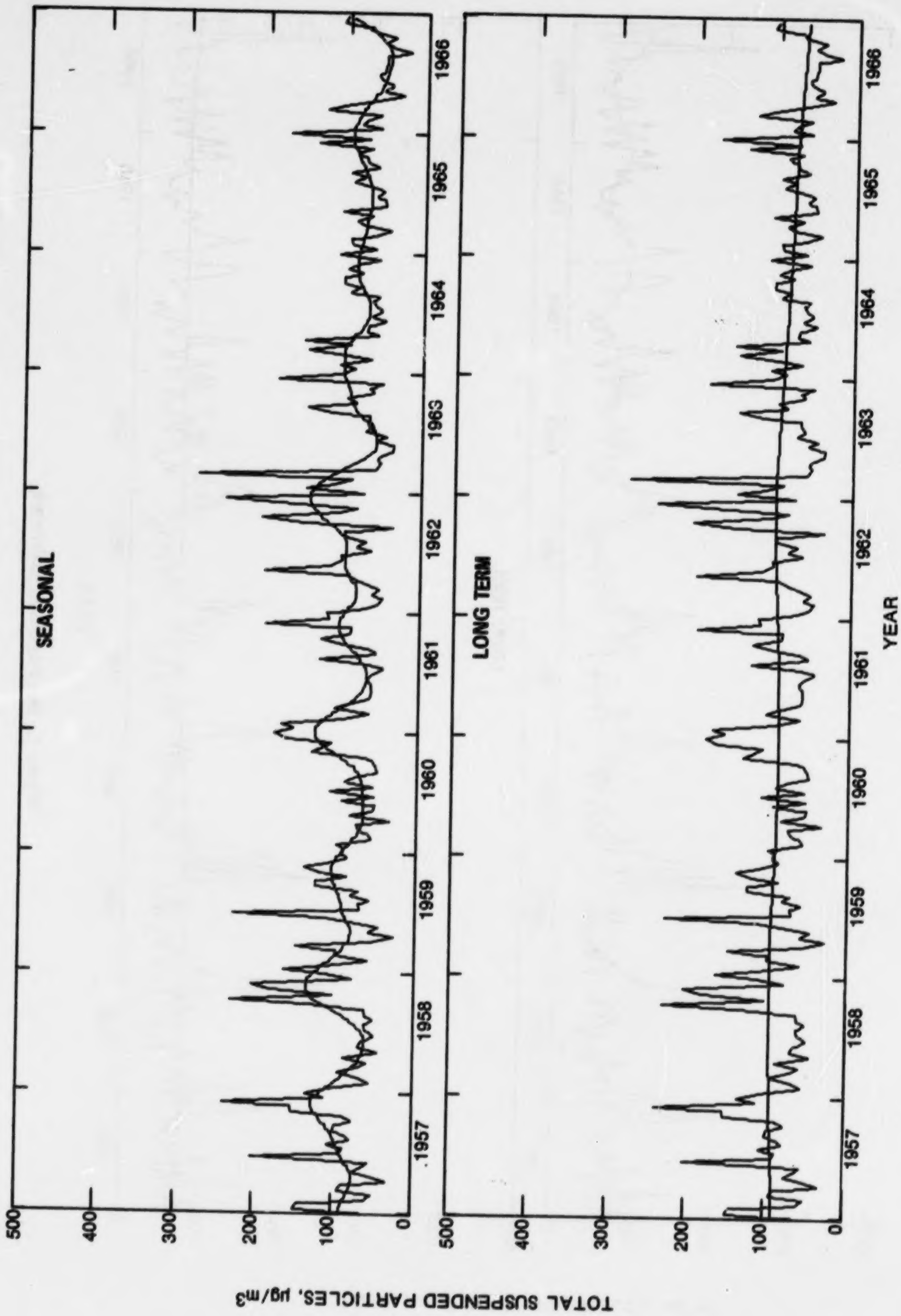


Figure 7. San Diego, California.

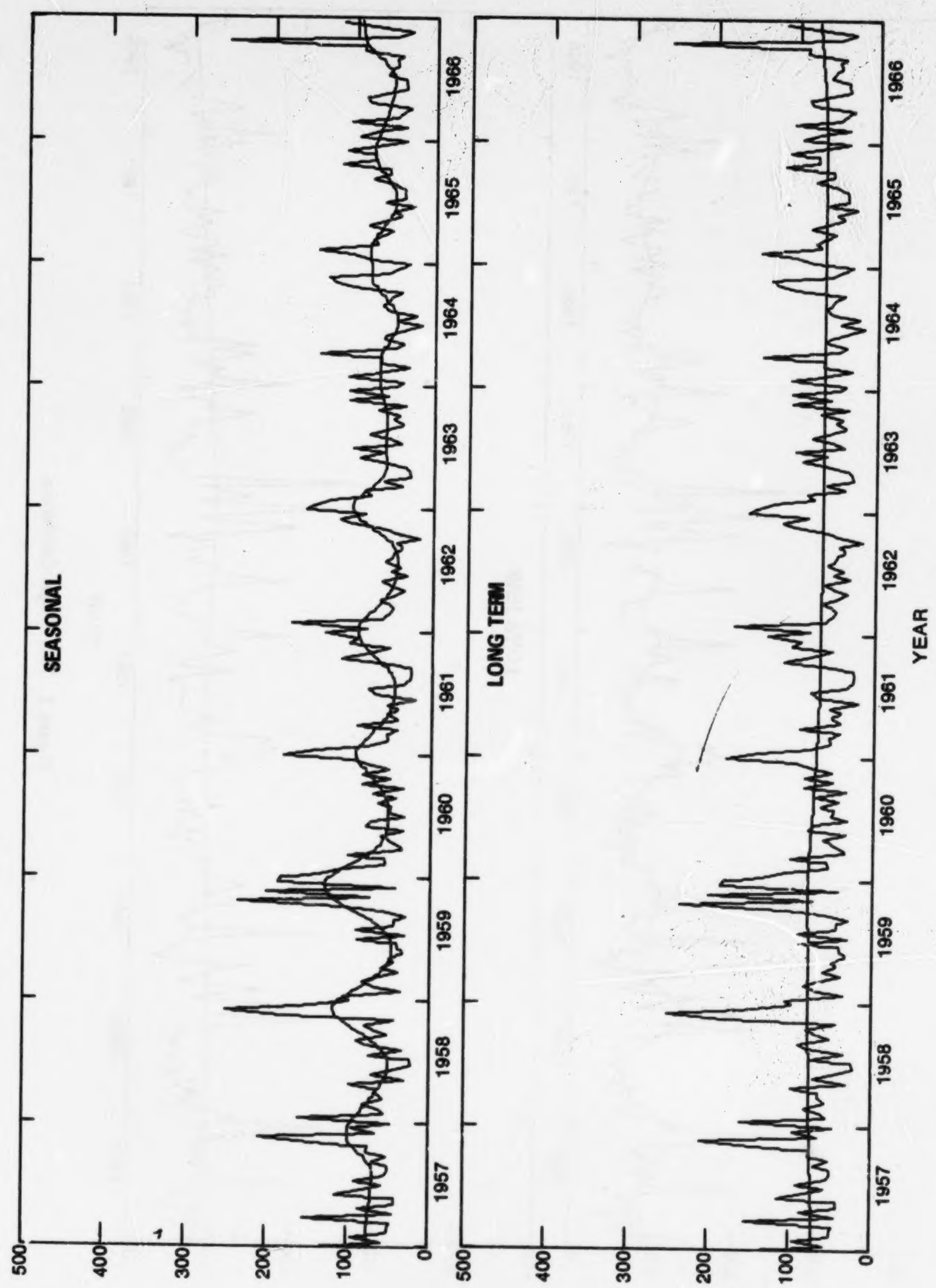


Figure 8. San Francisco, California.

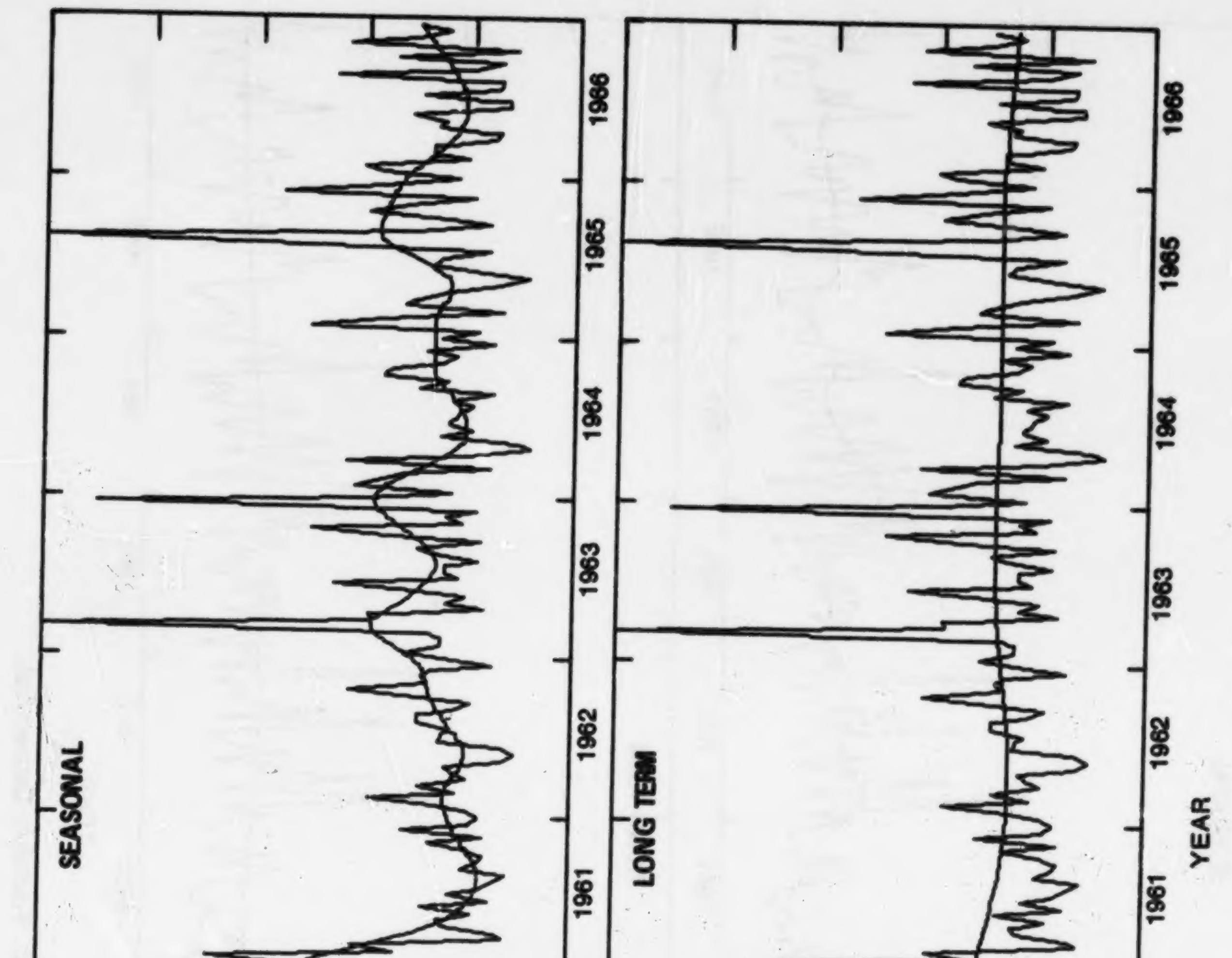


Figure 9. Denver, Colorado.

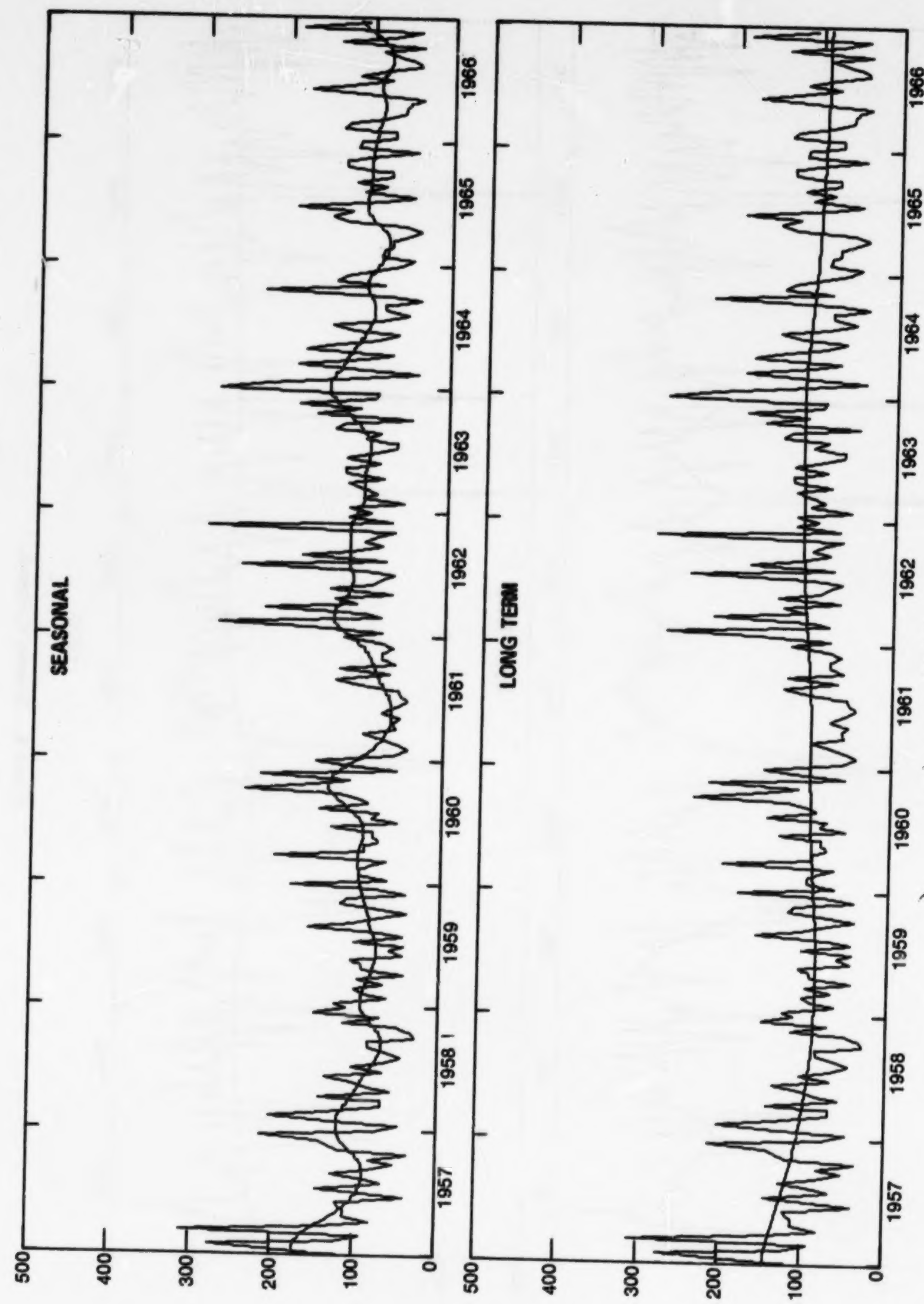
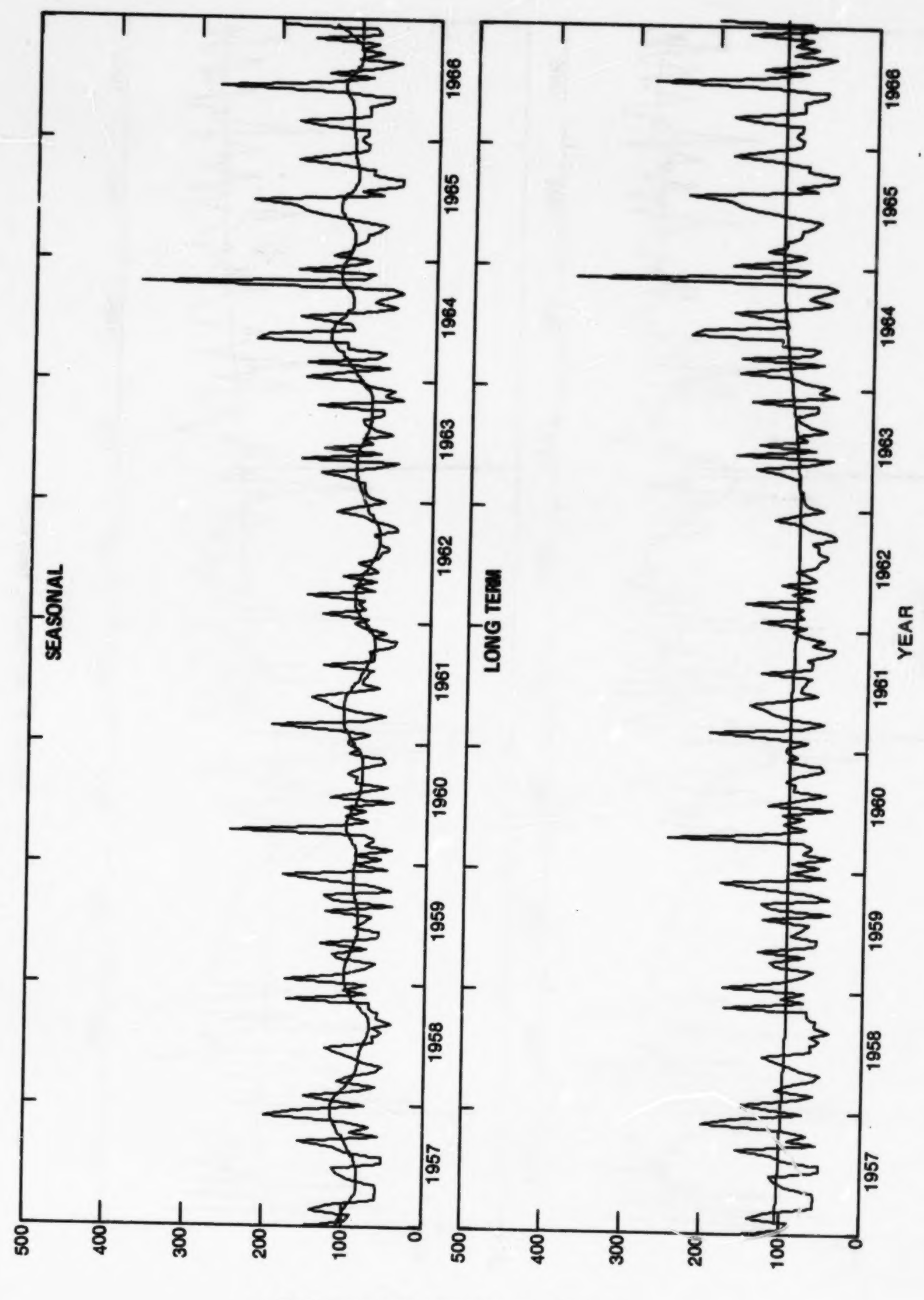


Figure 10. Hartford, Connecticut.



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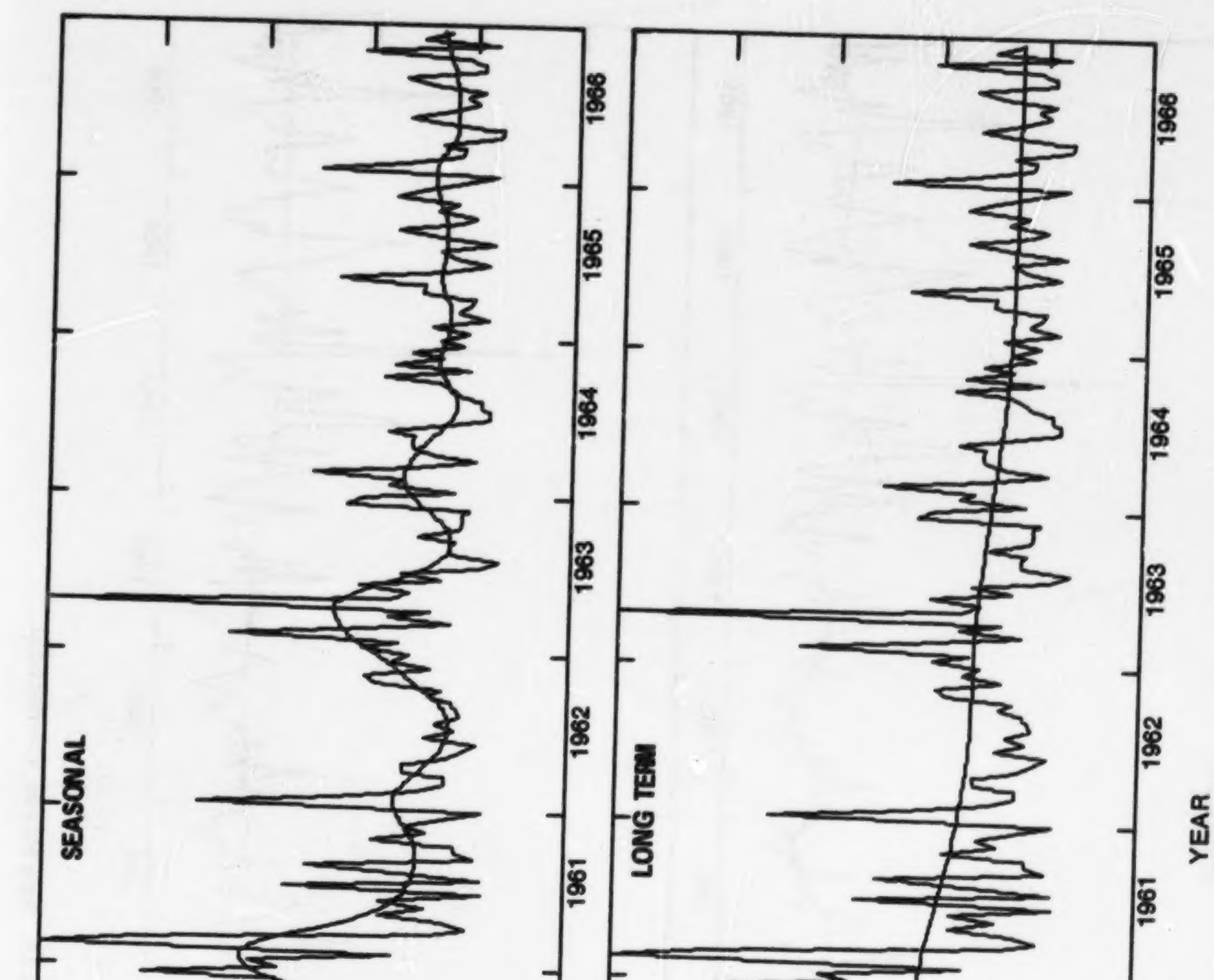


Figure 12. Wilmington, Delaware

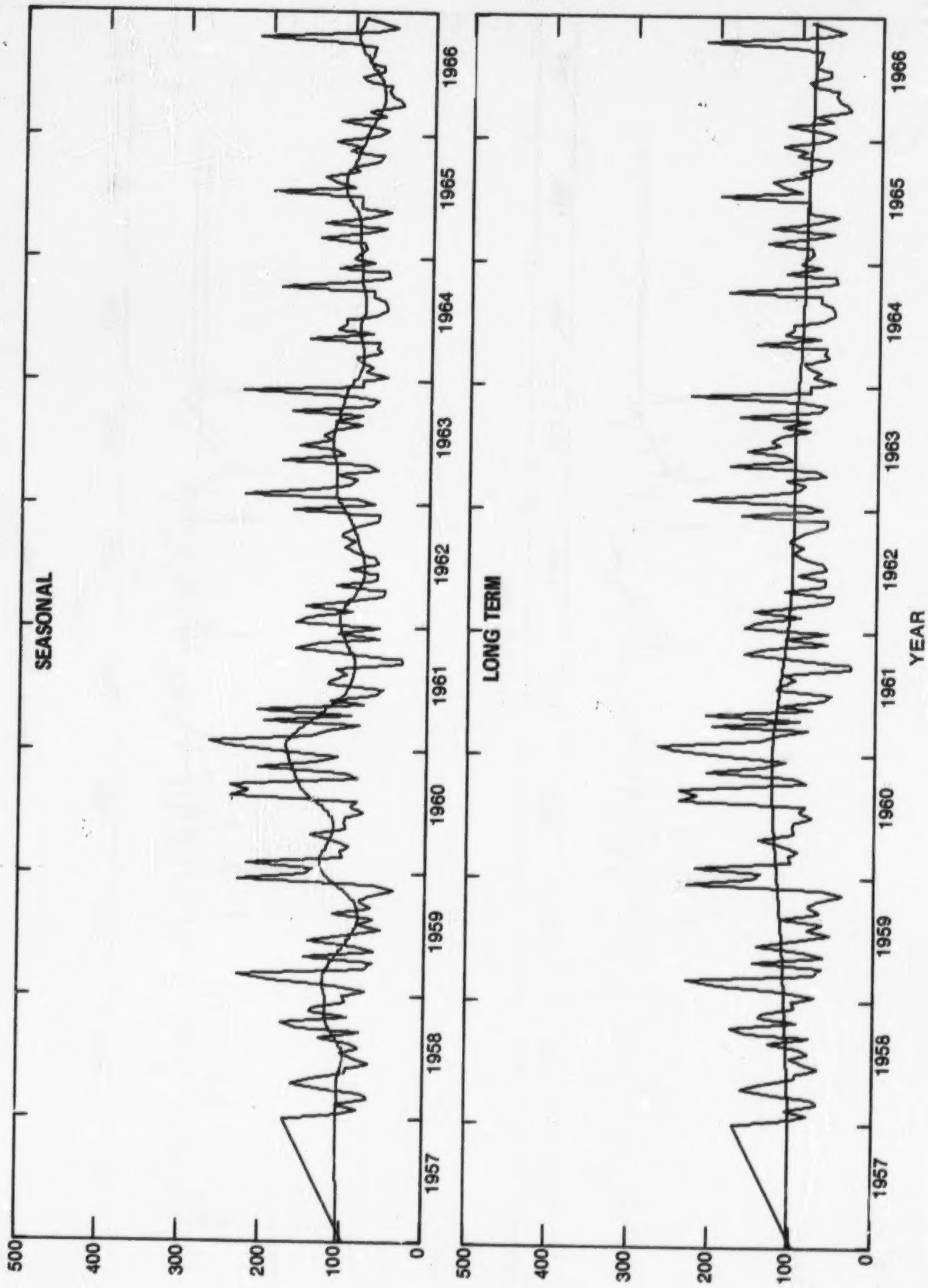


Figure 13. Washington, D. C.

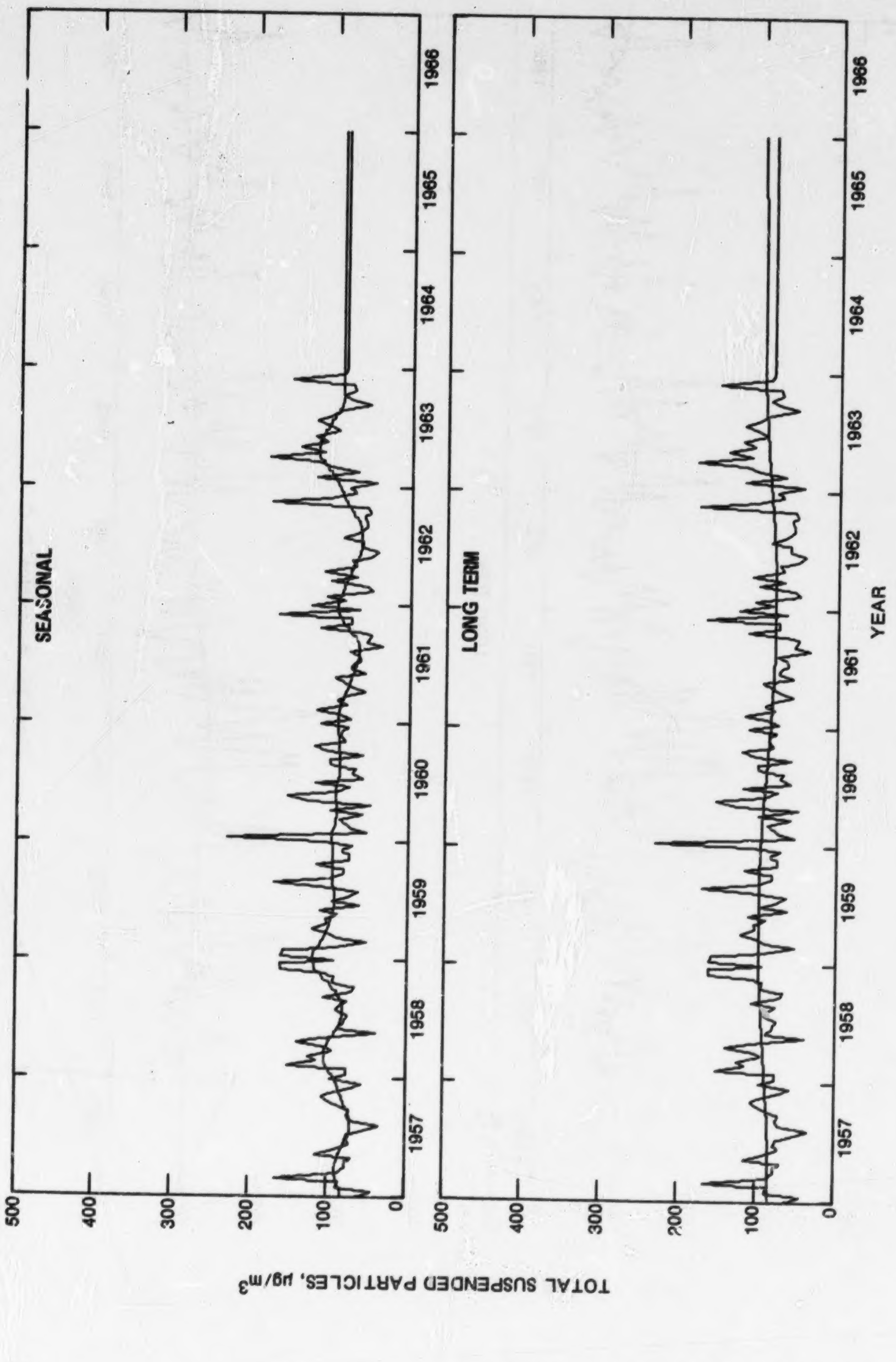


Figure 14. Tampa, Florida.

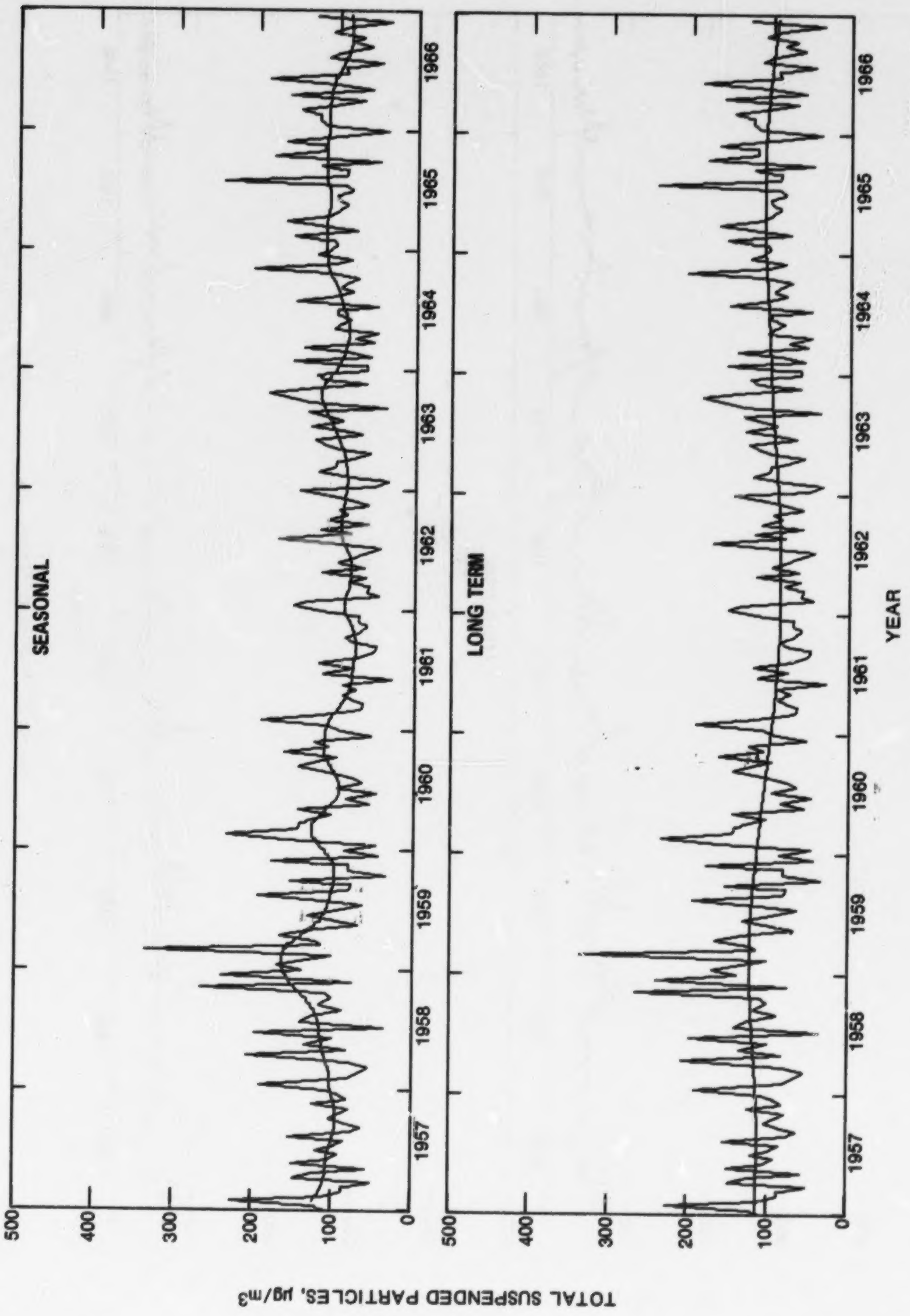


Figure 15. Atlanta, Georgia.

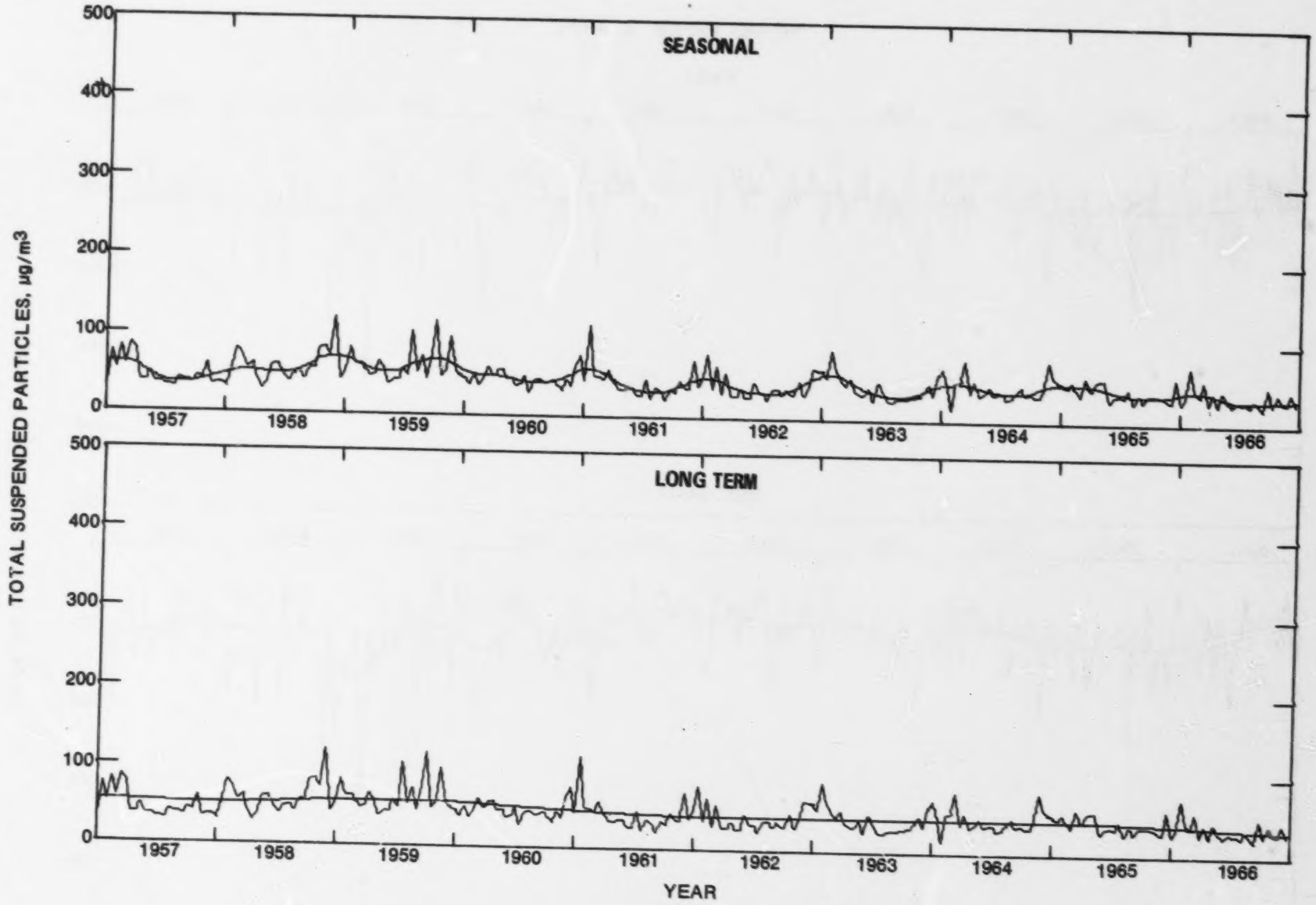
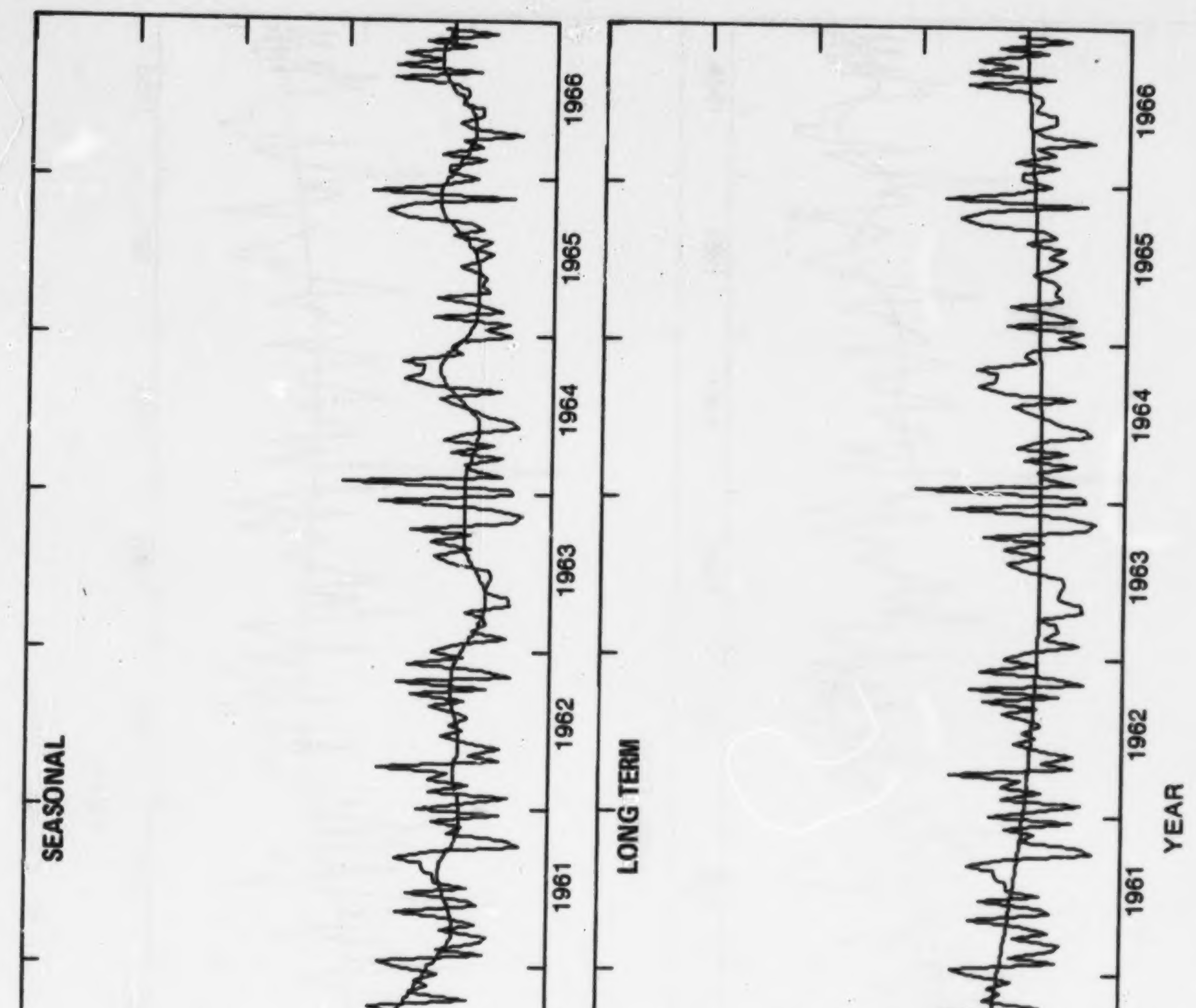


Figure 16. Honolulu, Hawaii.



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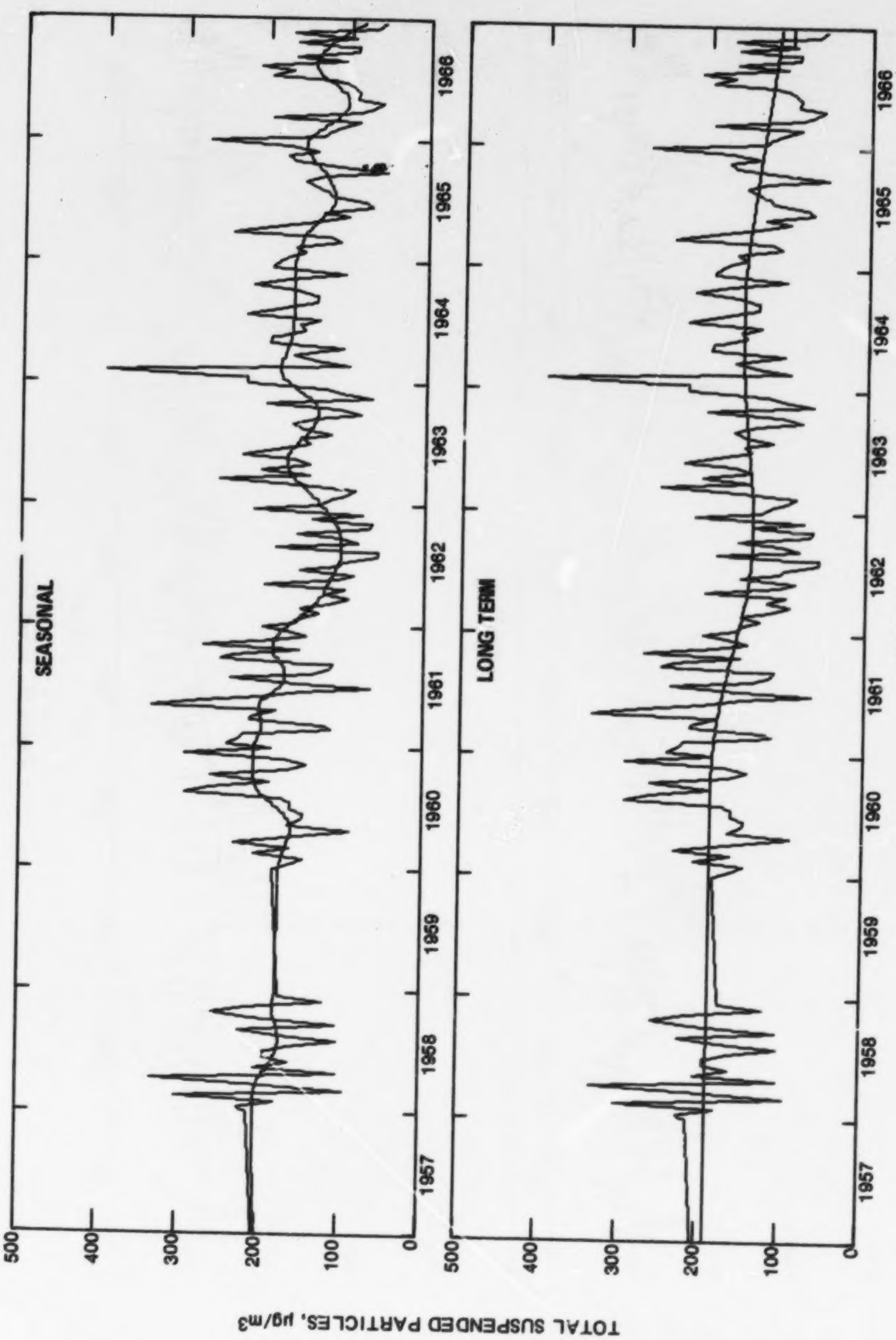

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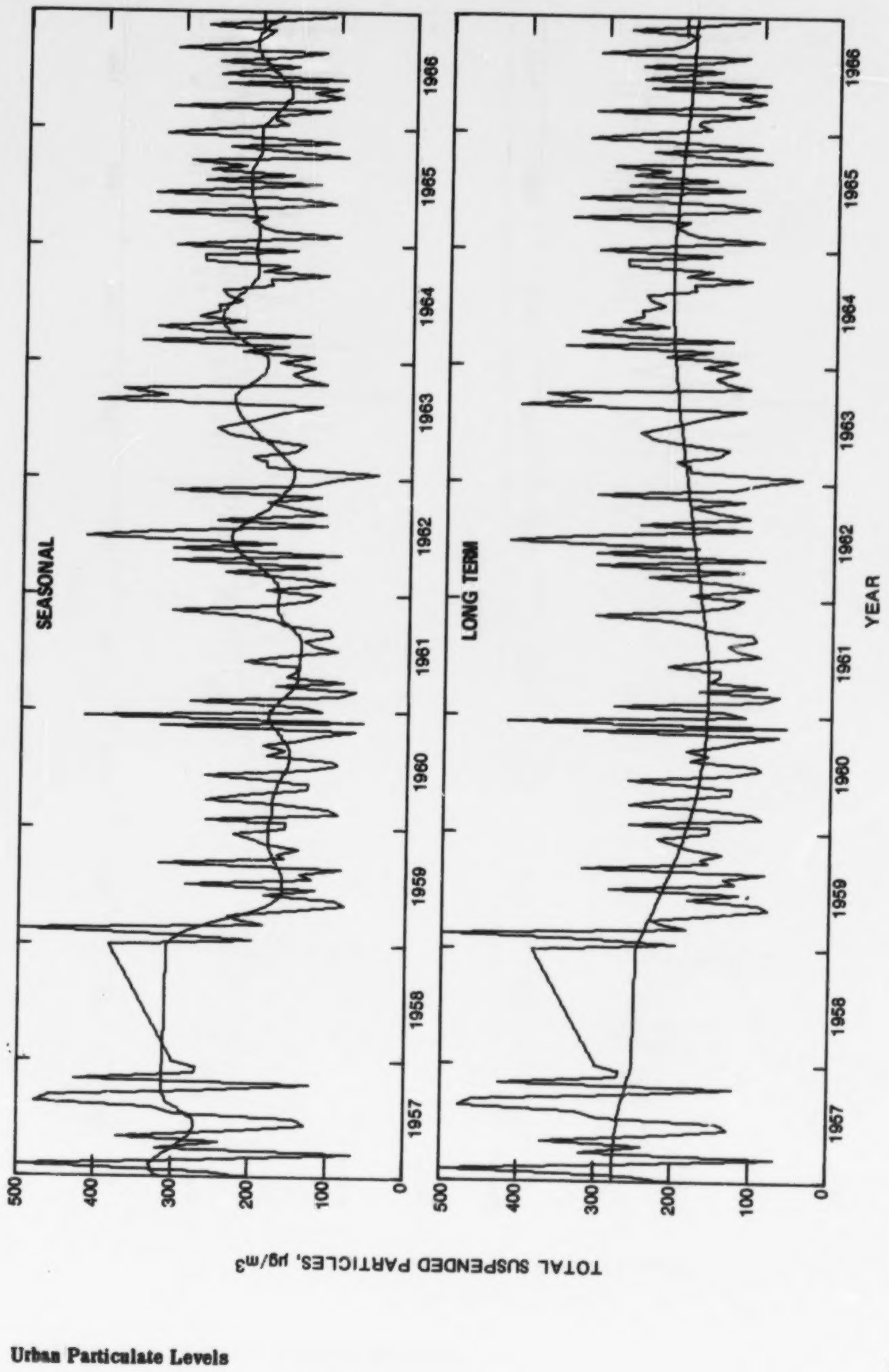

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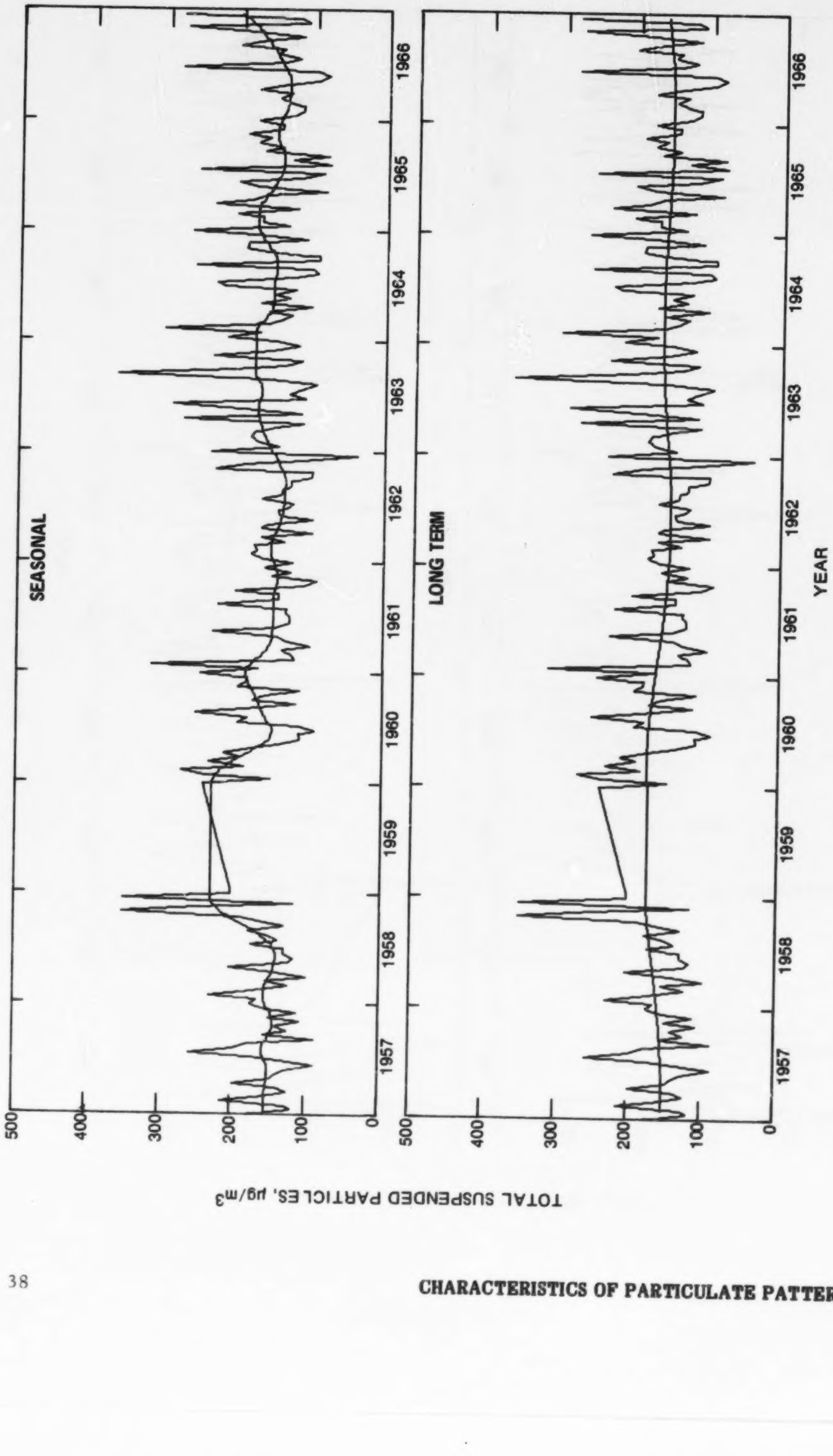

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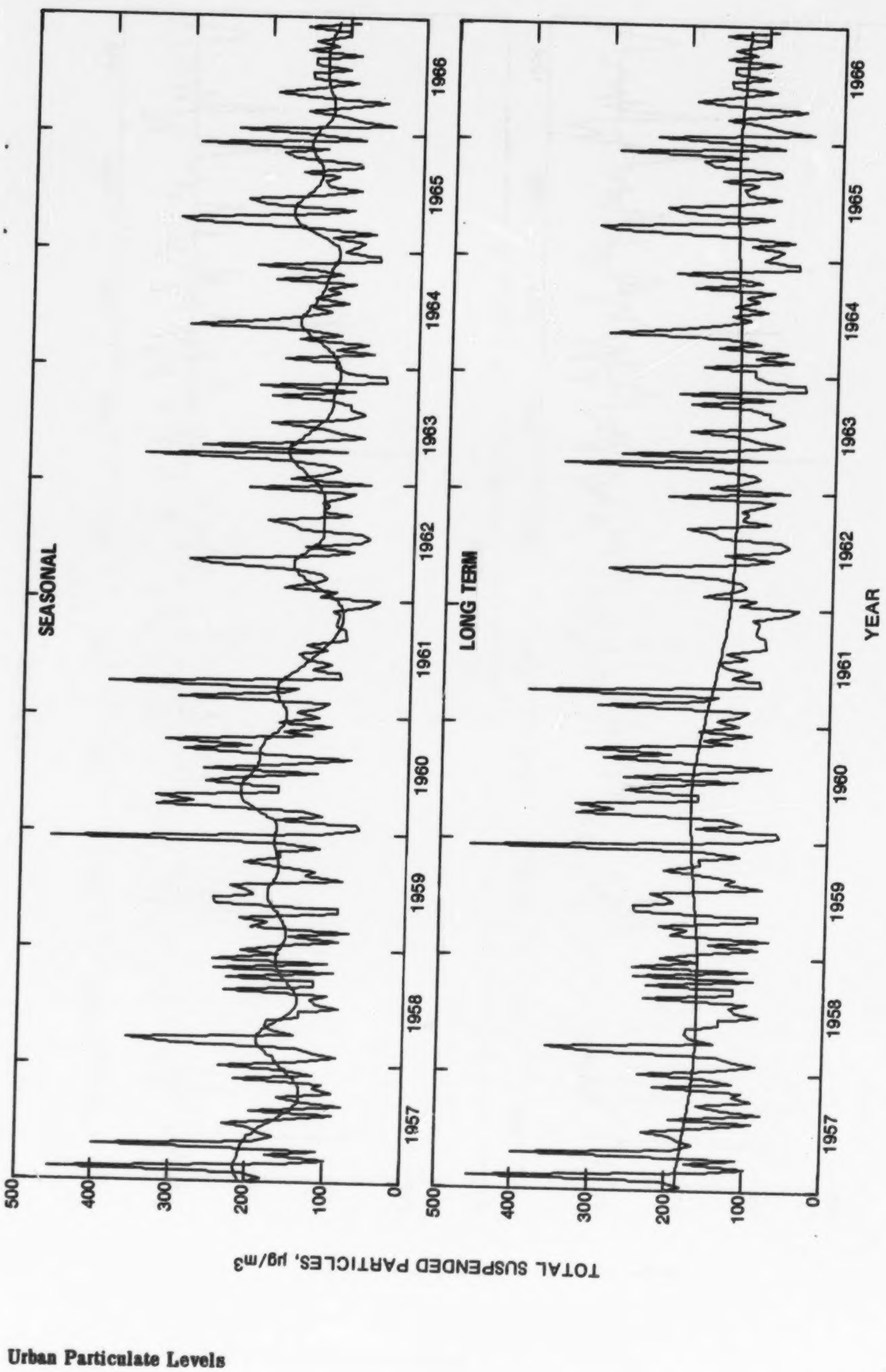

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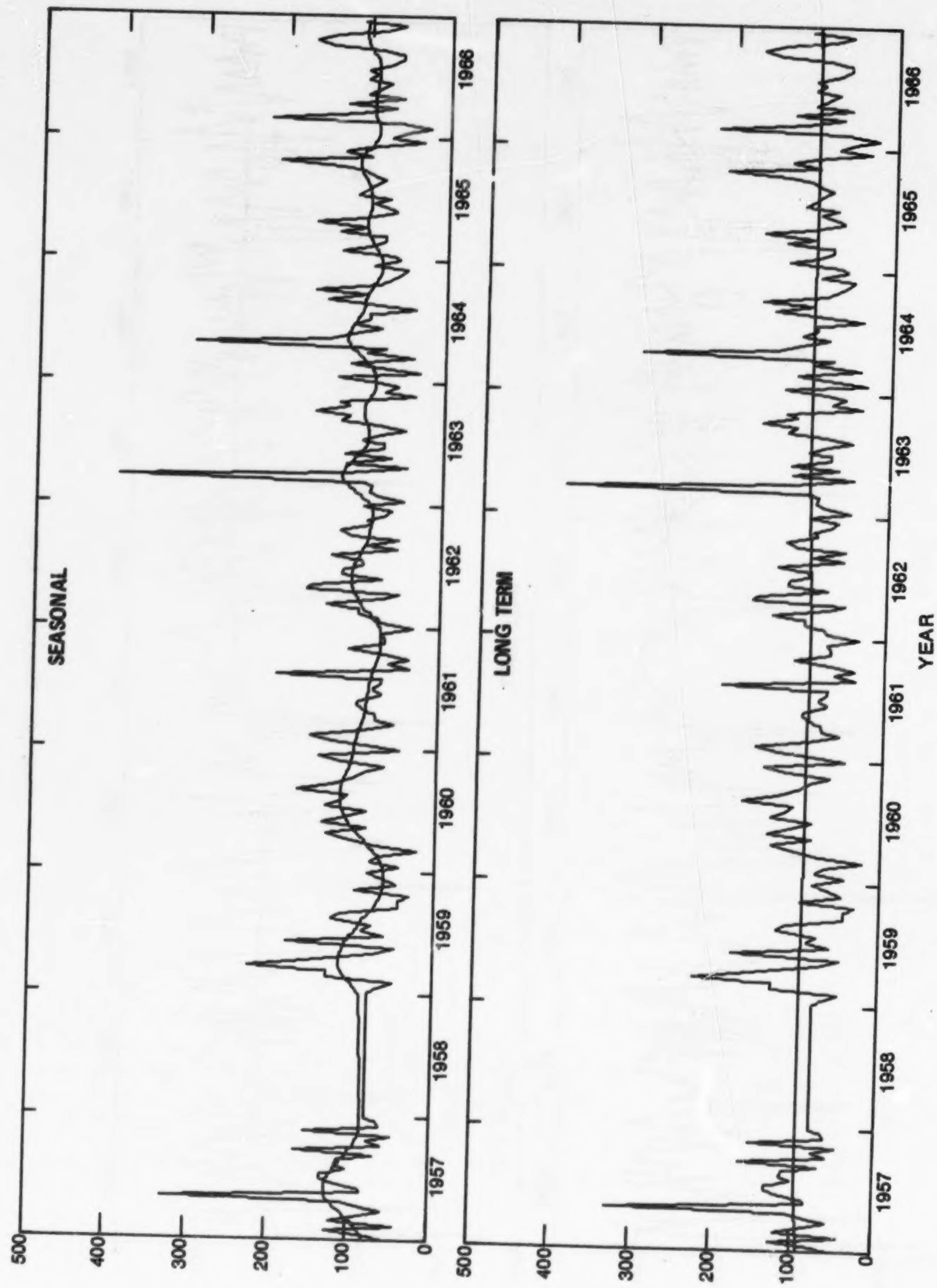

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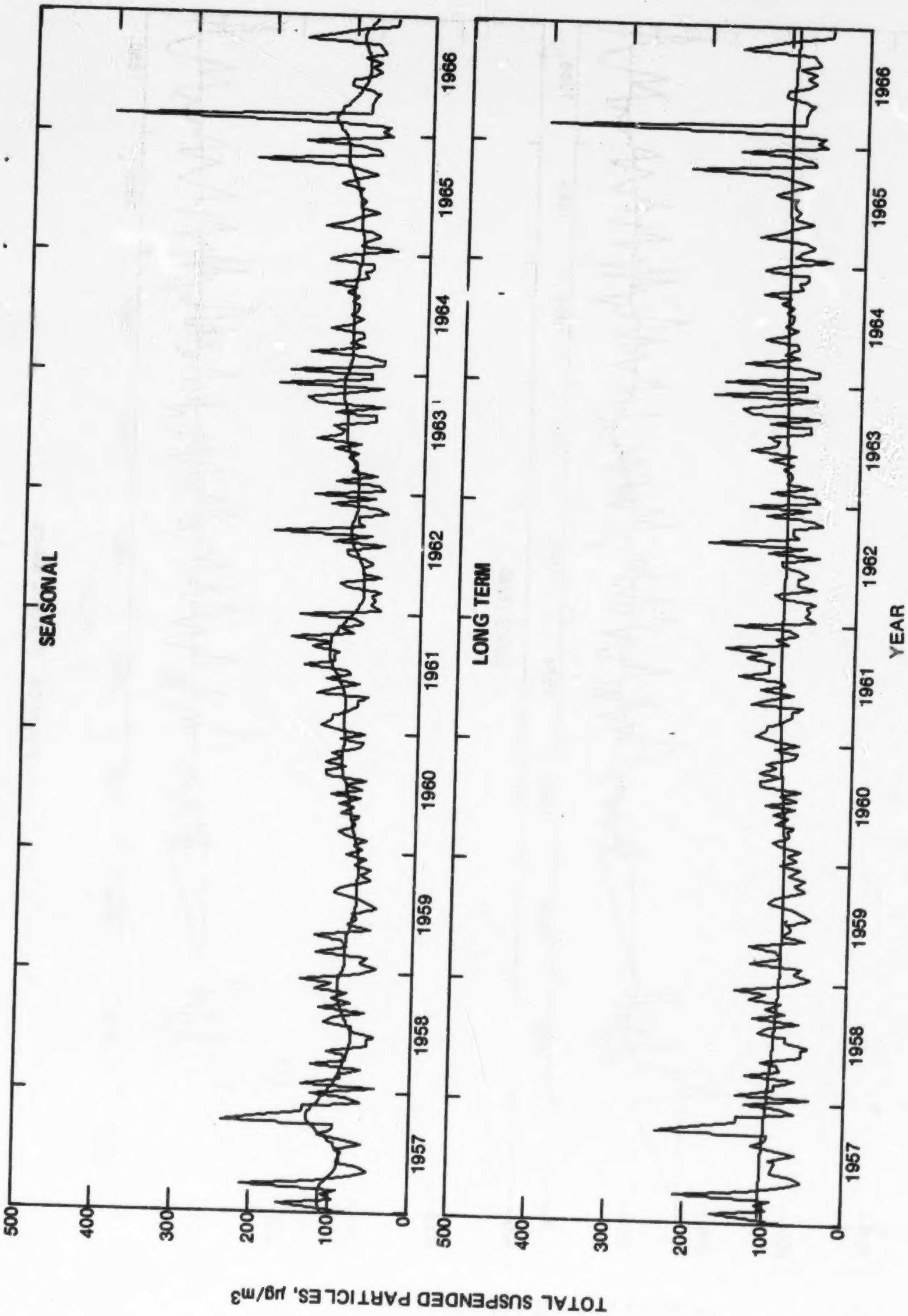

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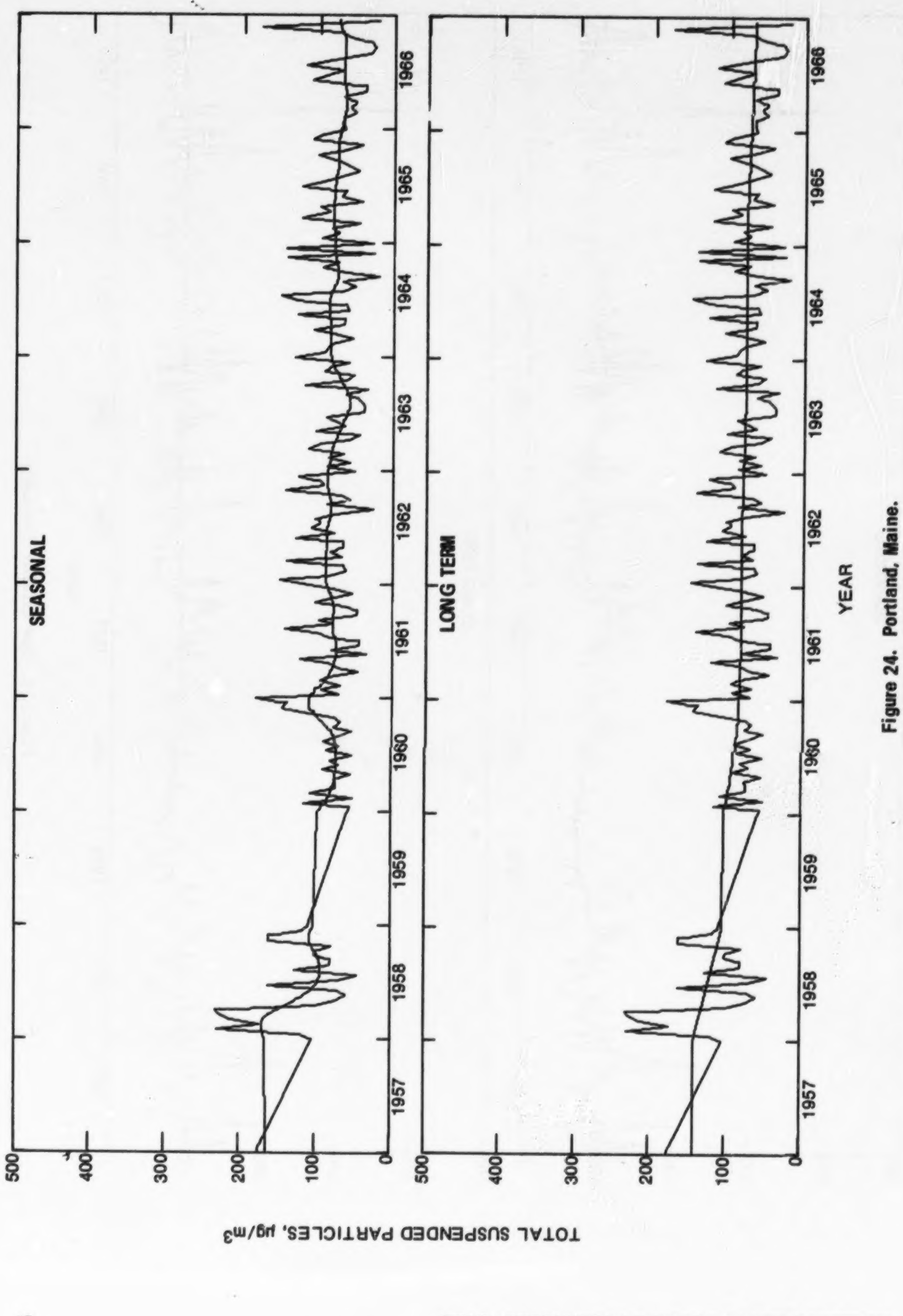

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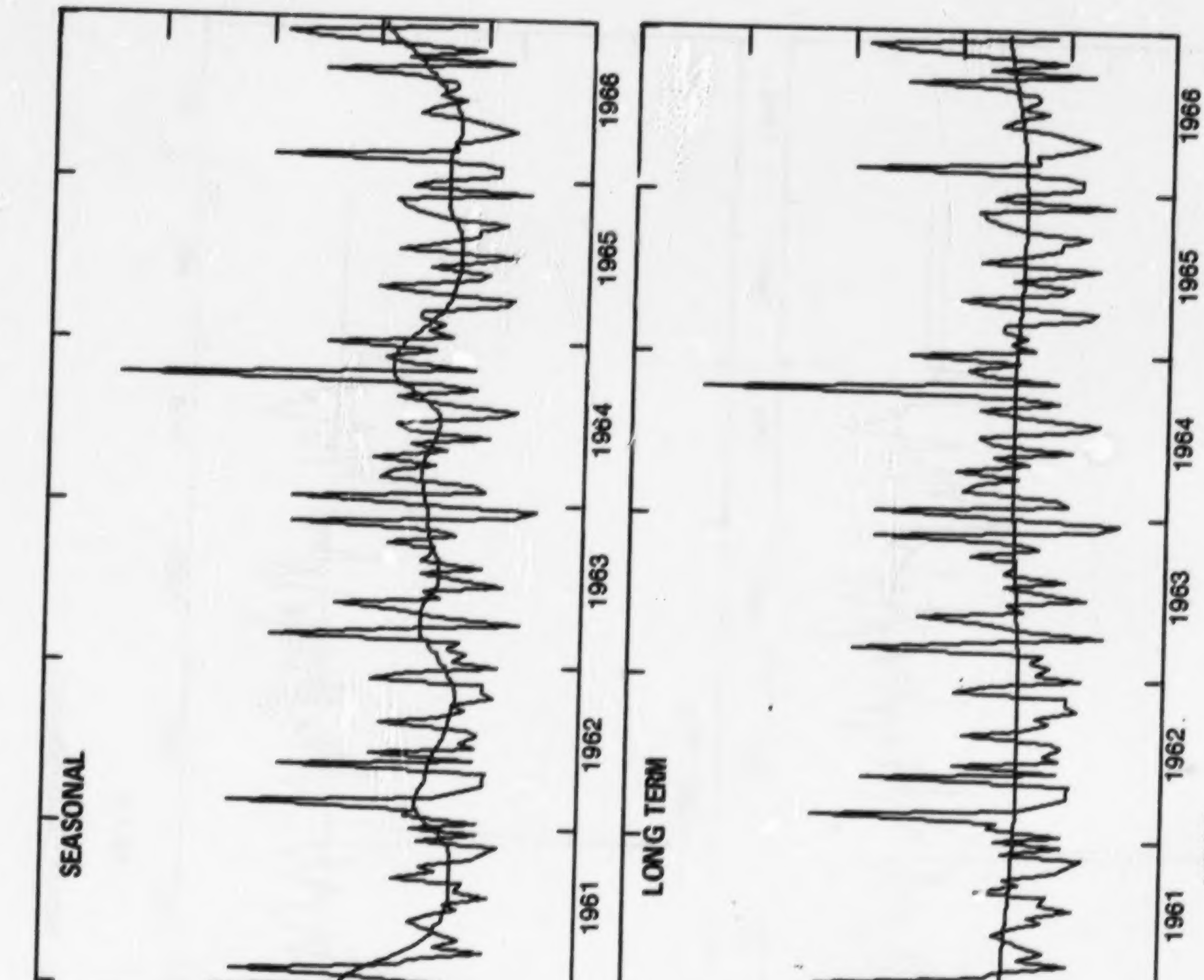

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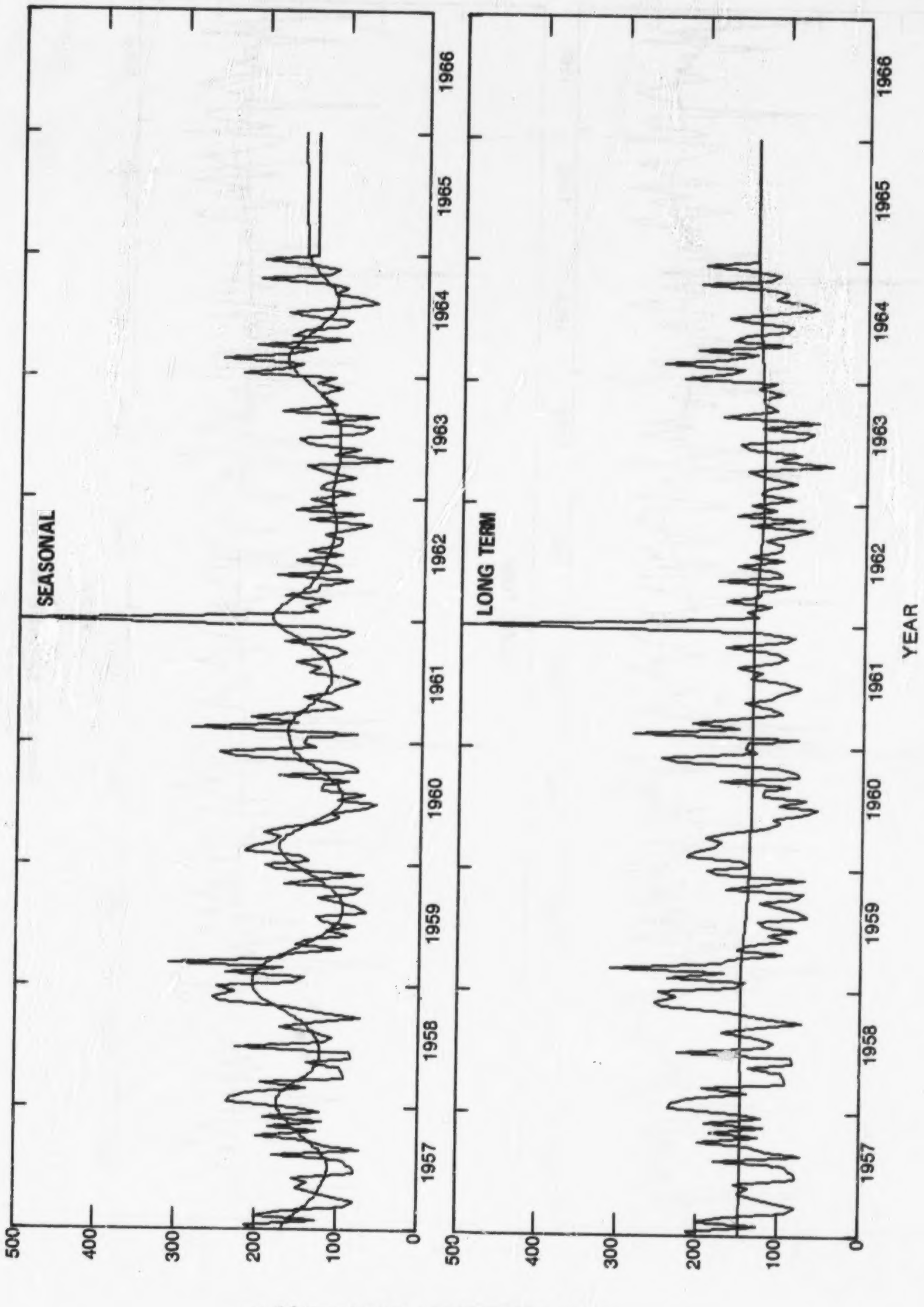

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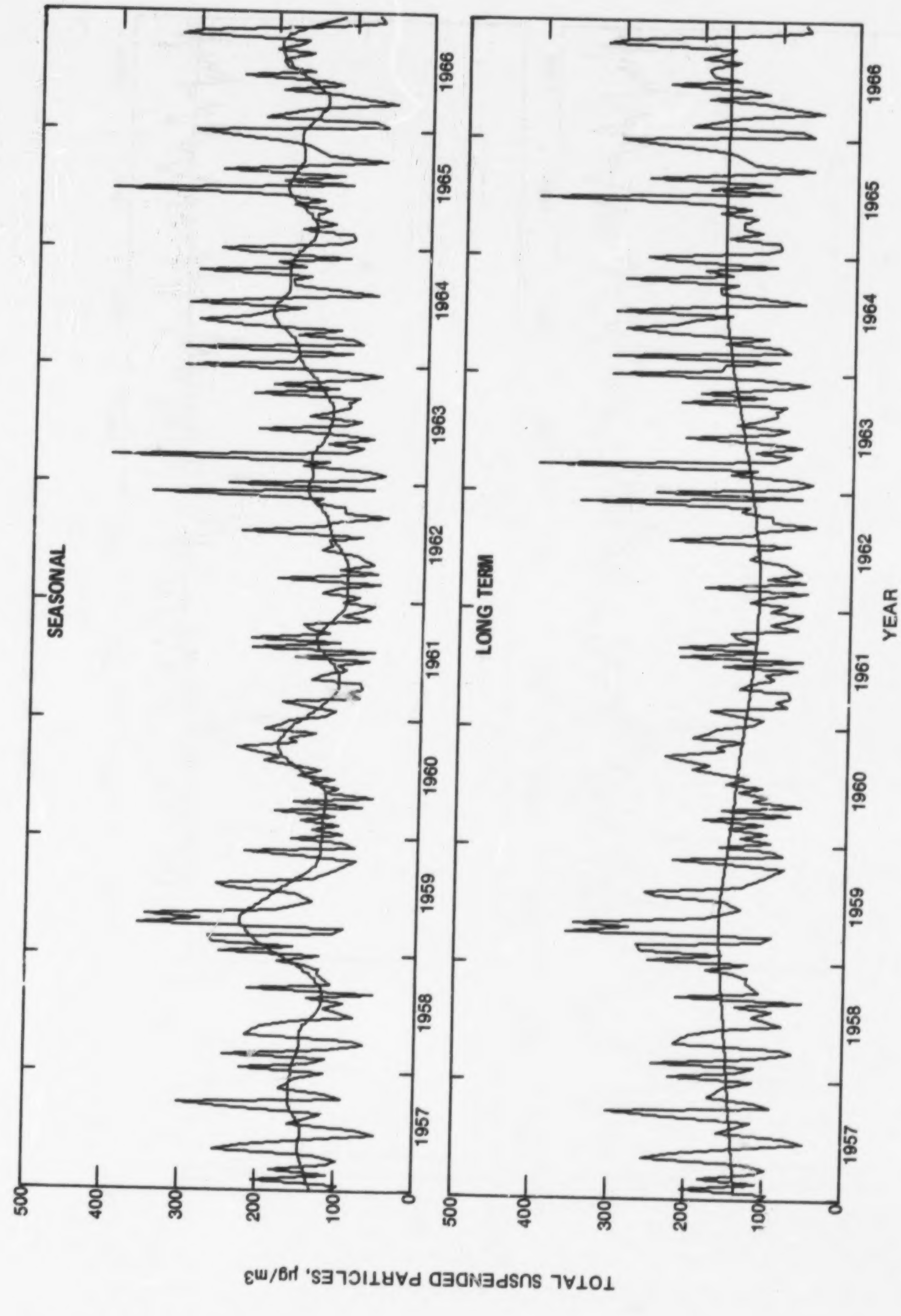

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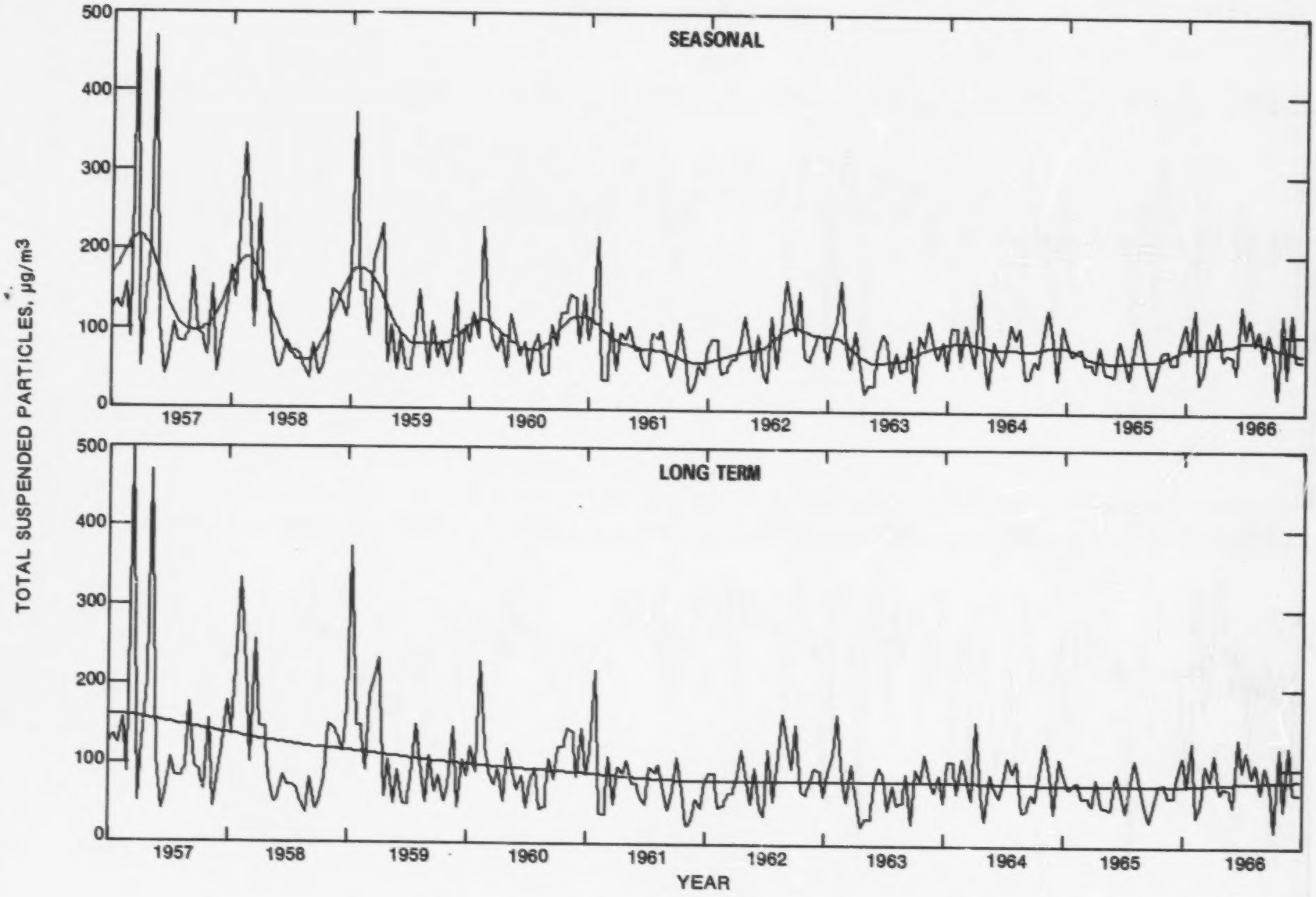

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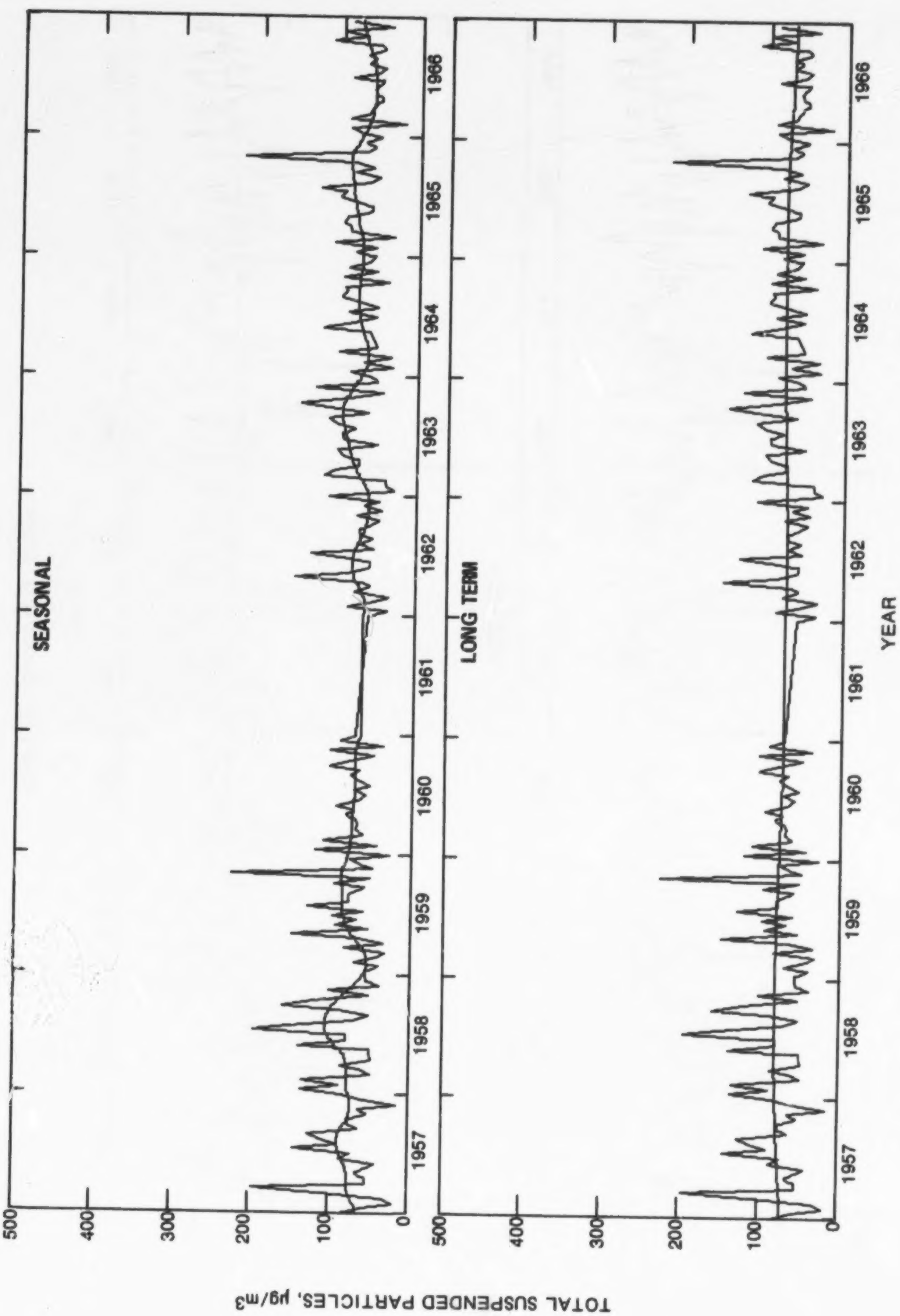

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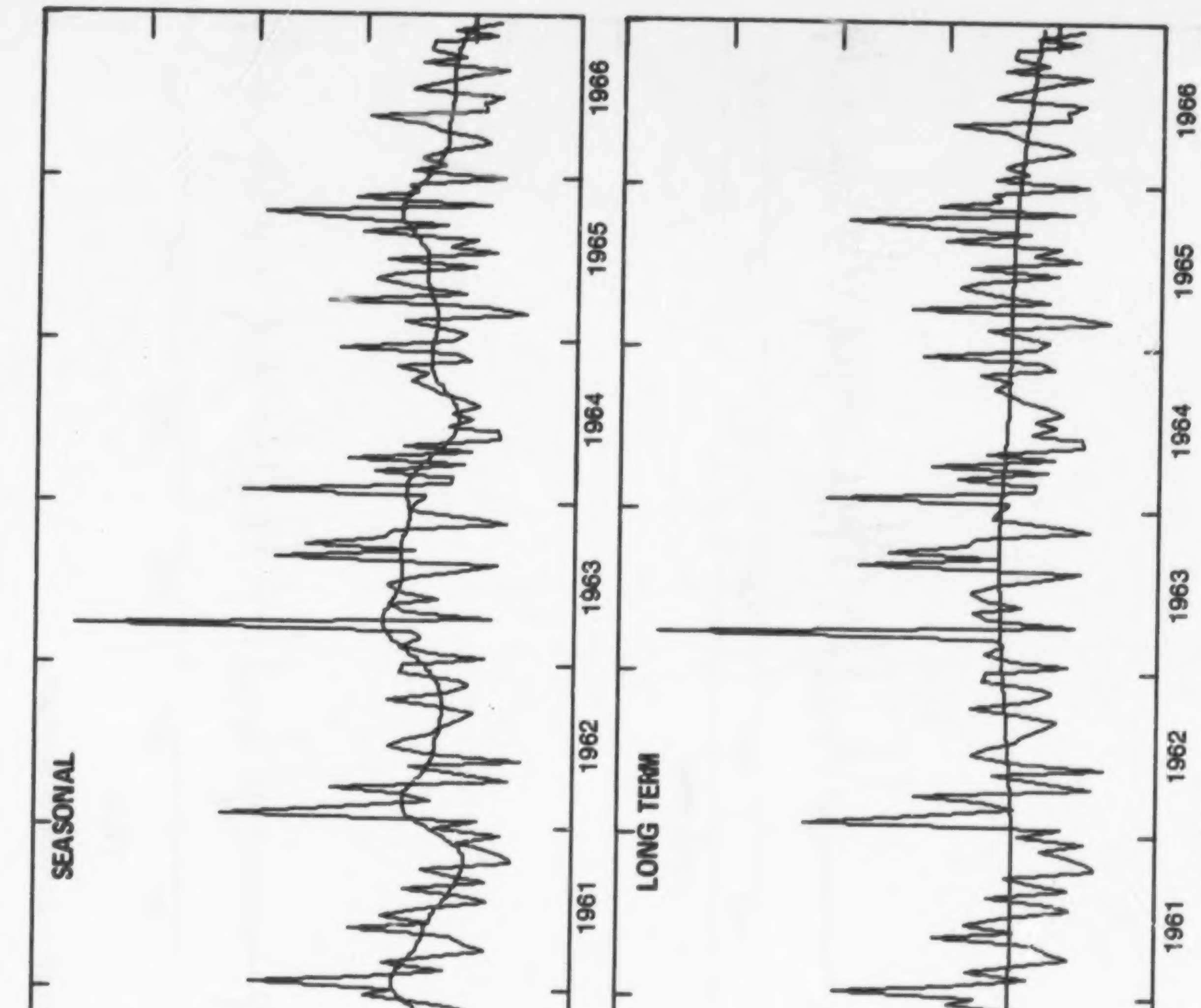
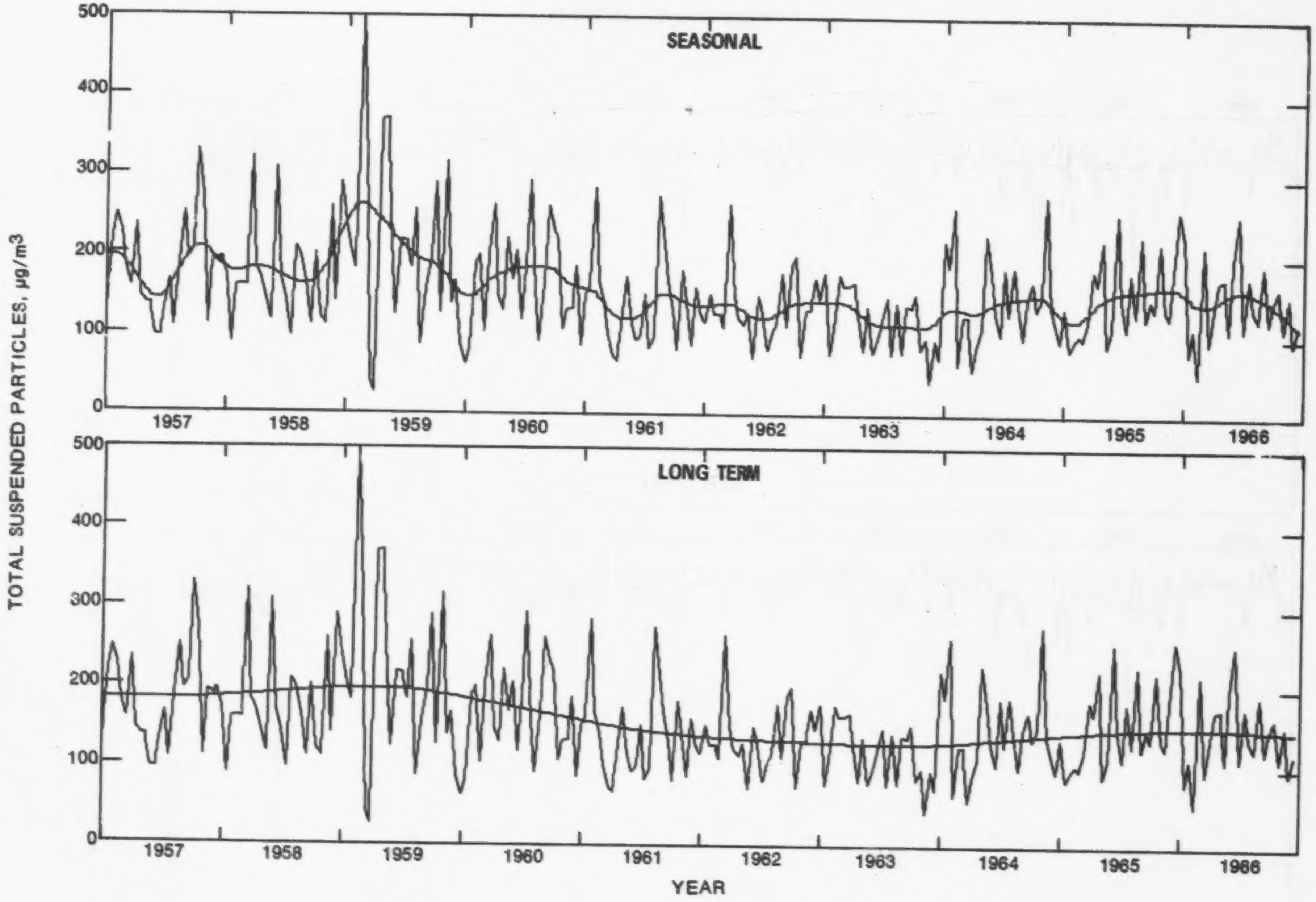


Figure 30. Kansas City, Missouri.



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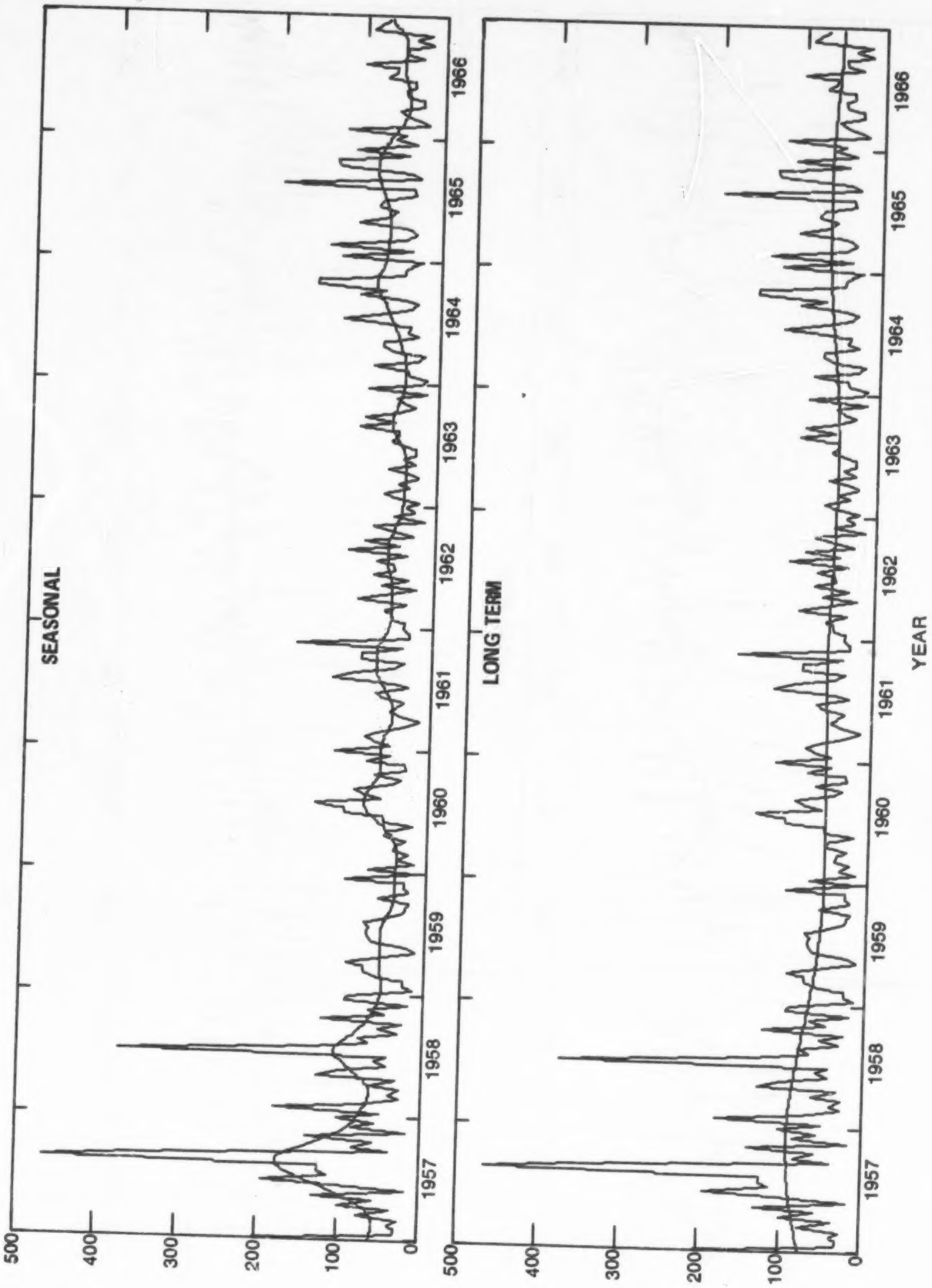
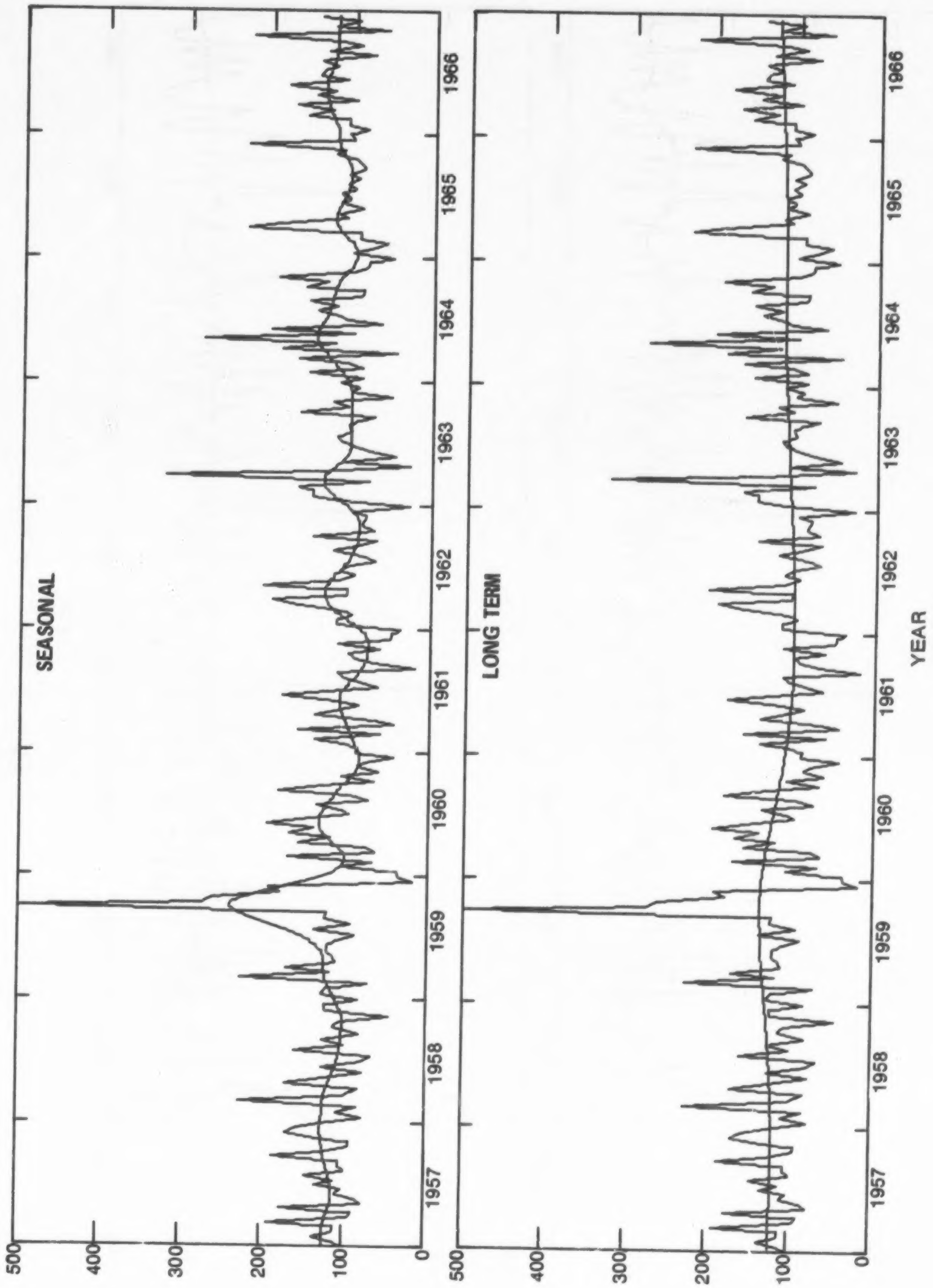


Figure 32. Helena, Montana.



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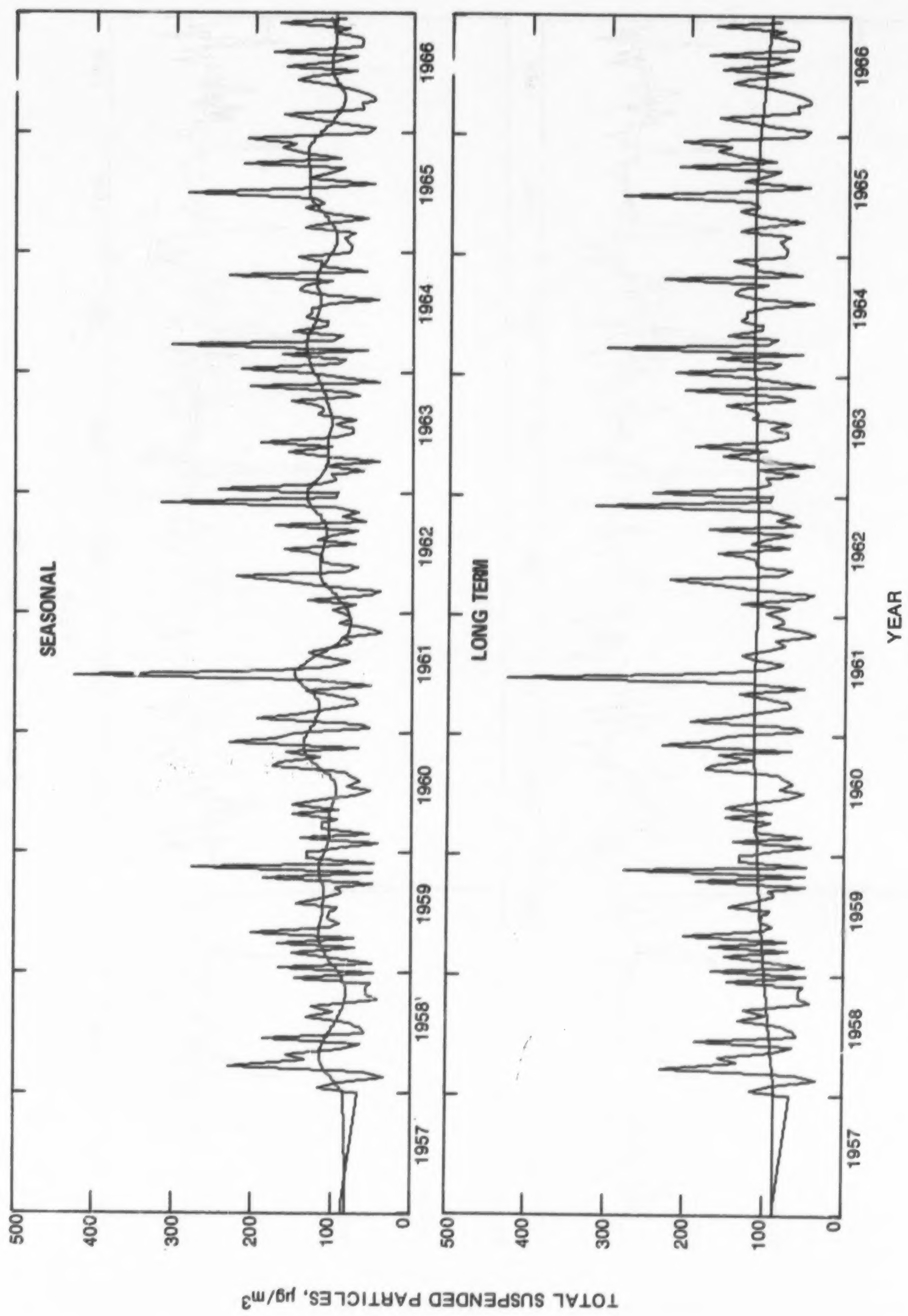

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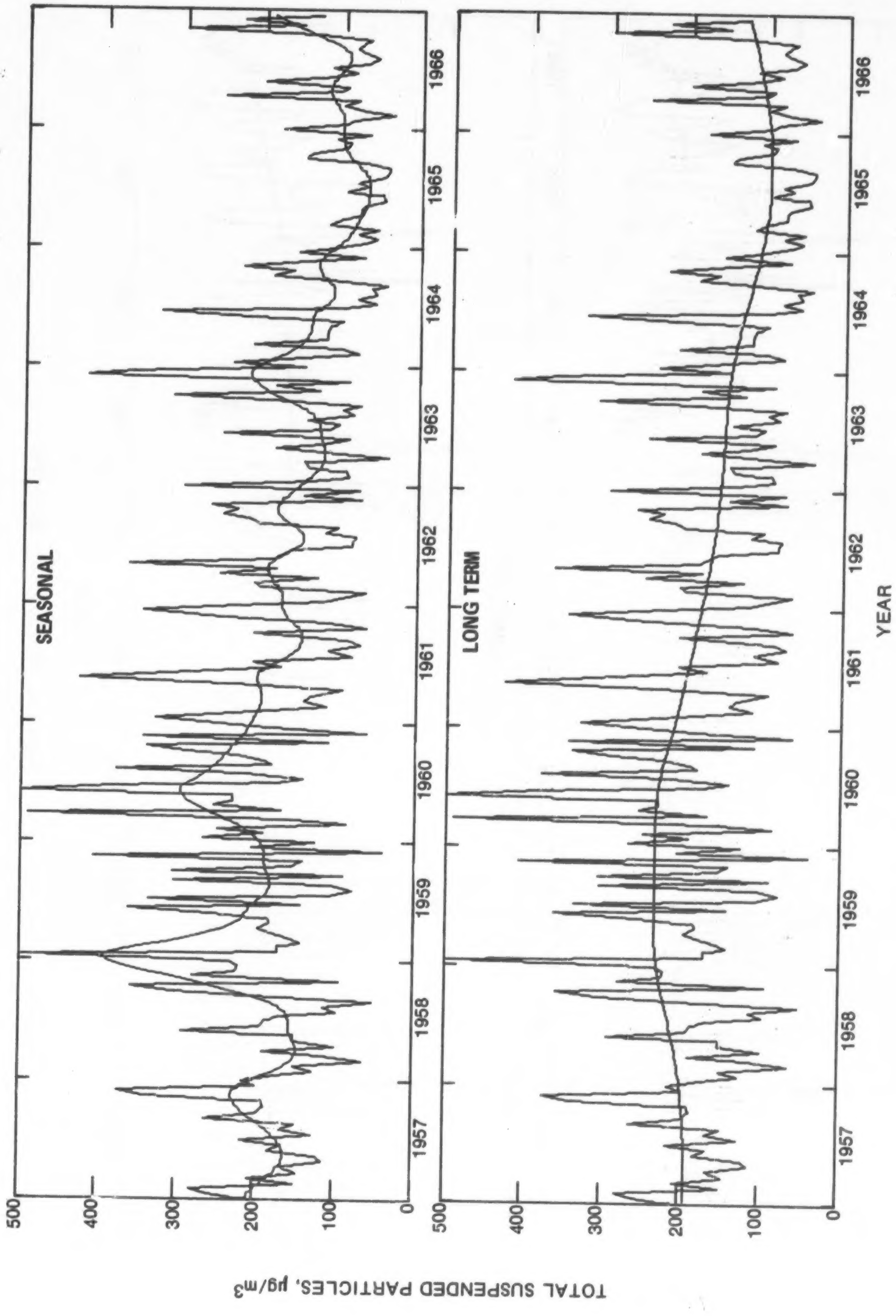

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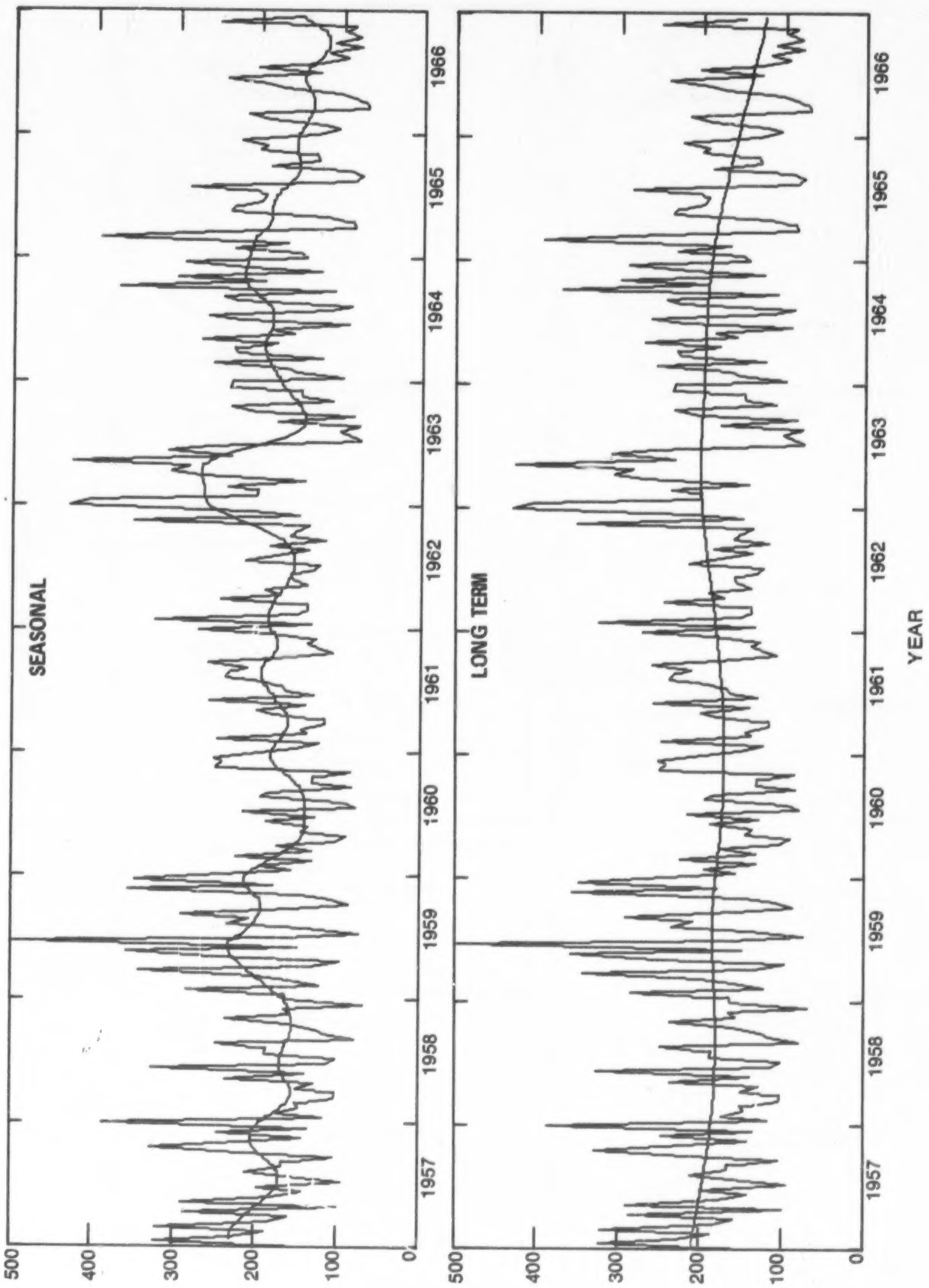
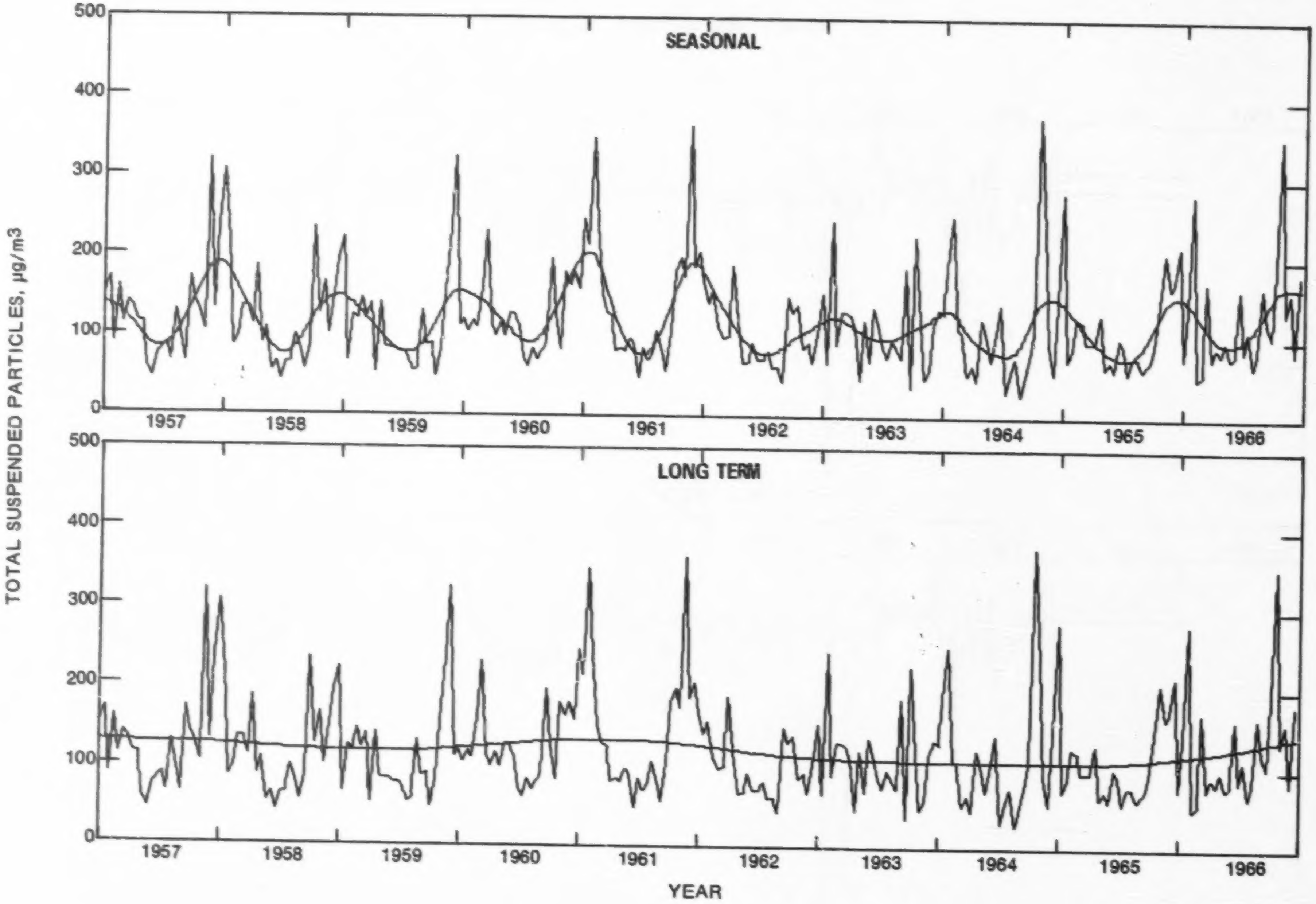


Figure 36. New York City, New York.



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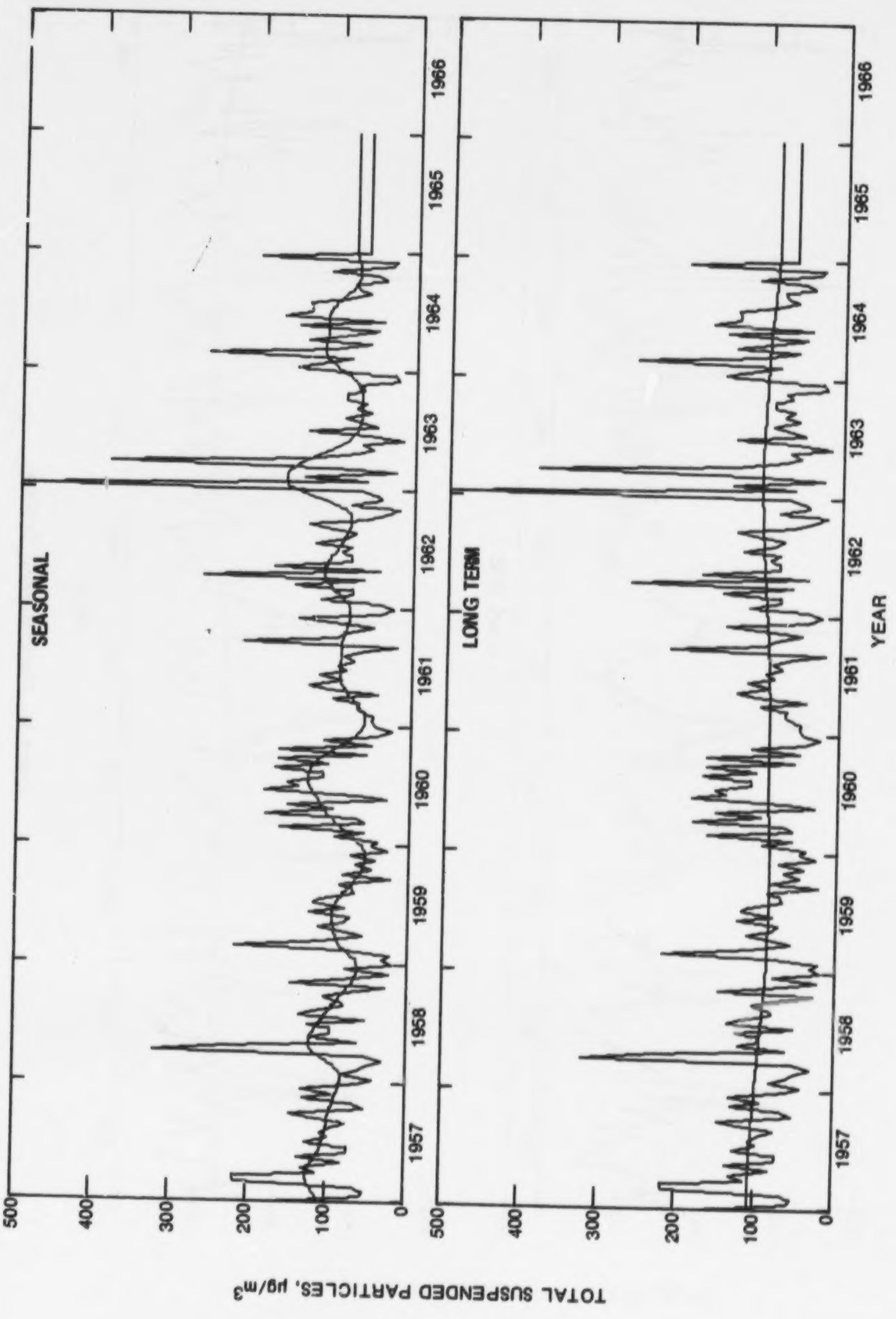

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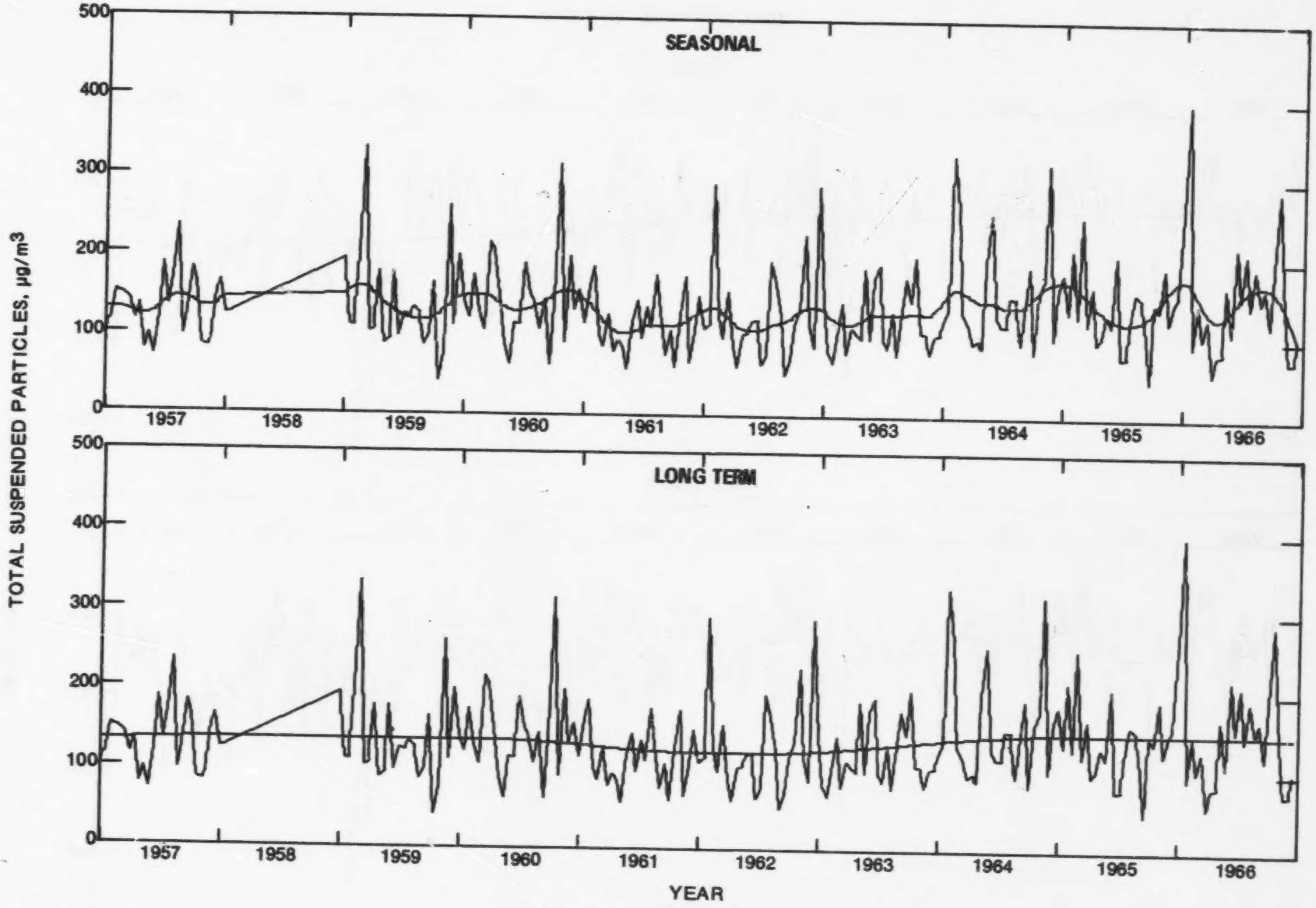
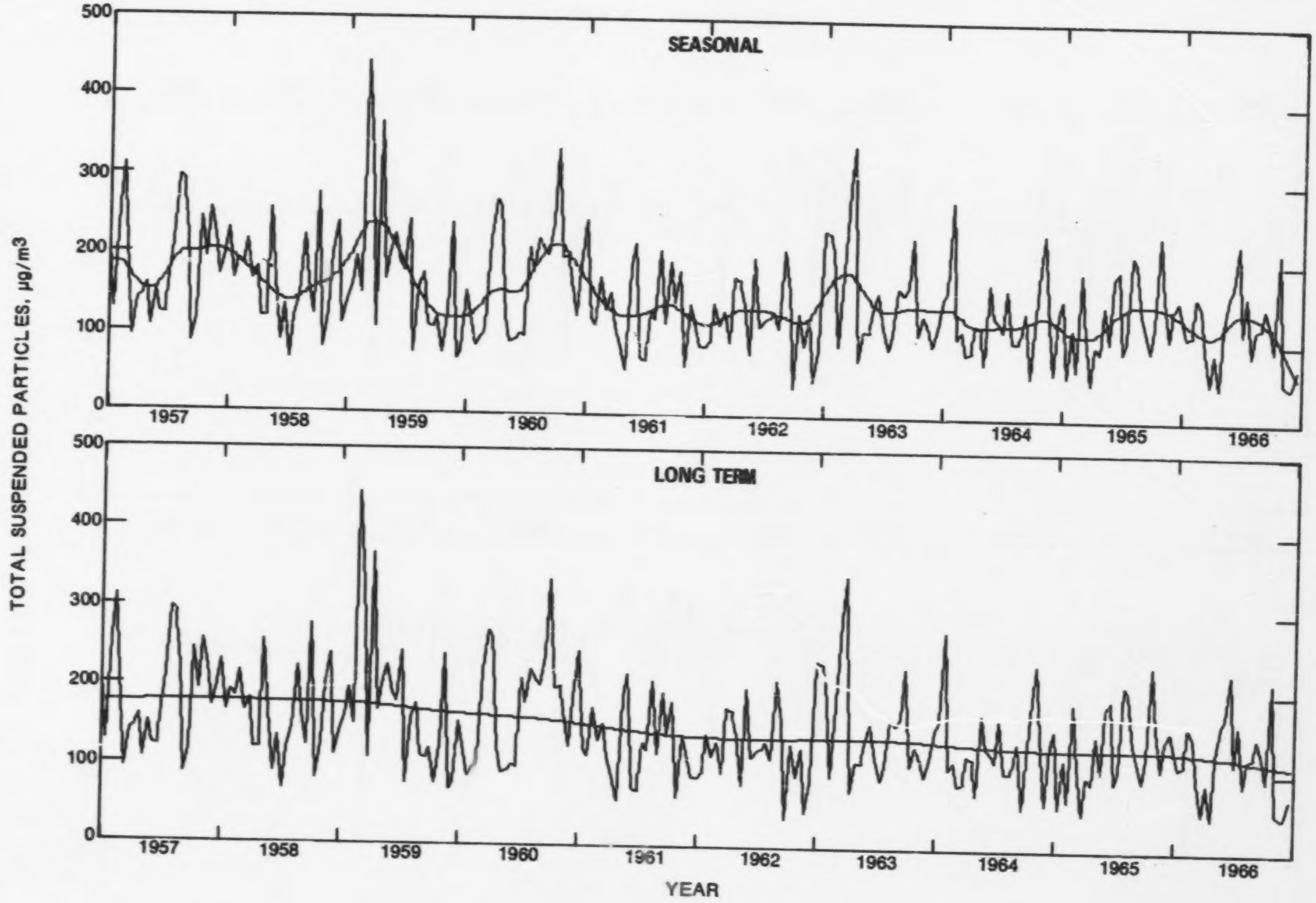


Figure 39. Cincinnati, Ohio.



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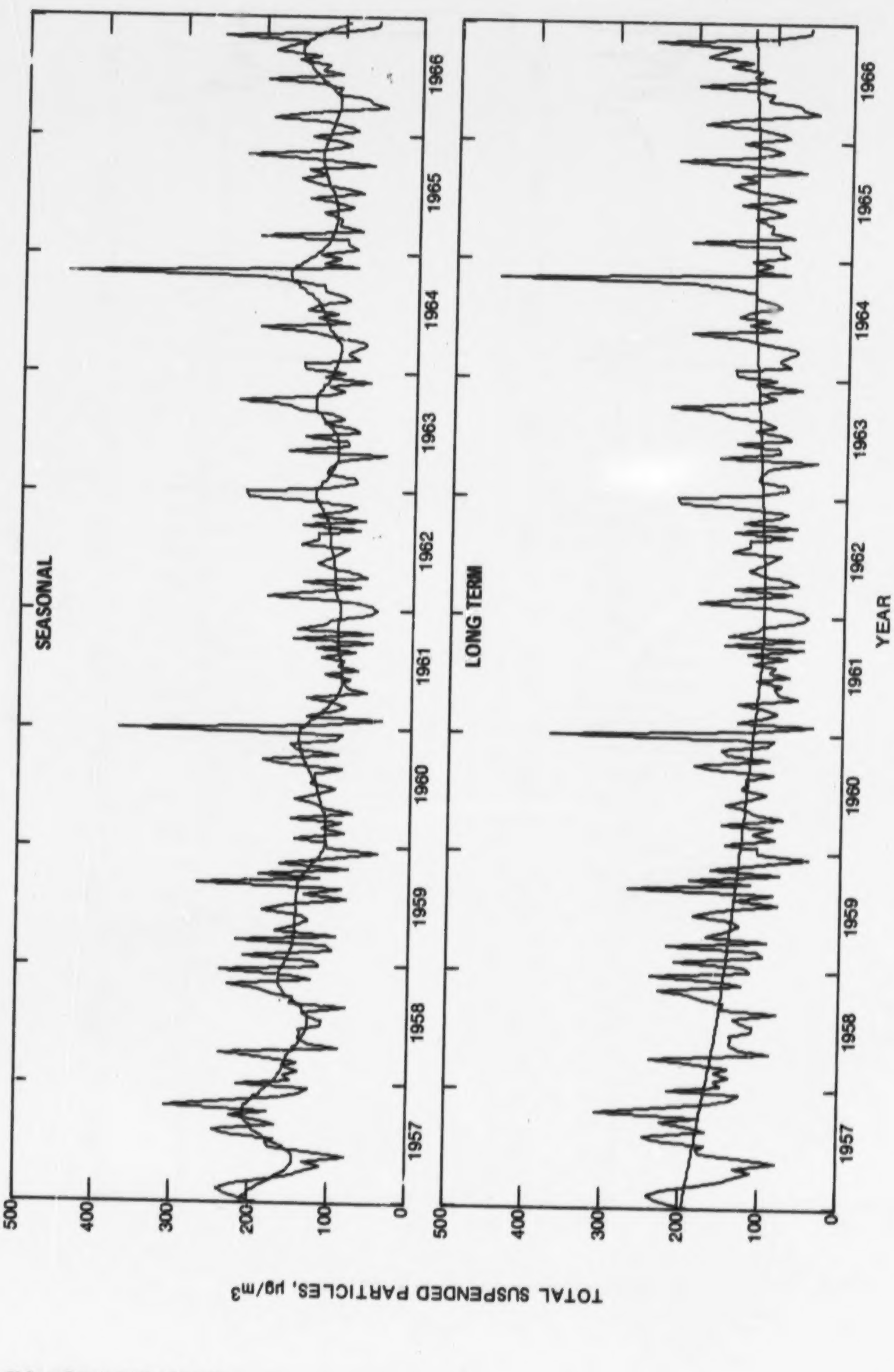

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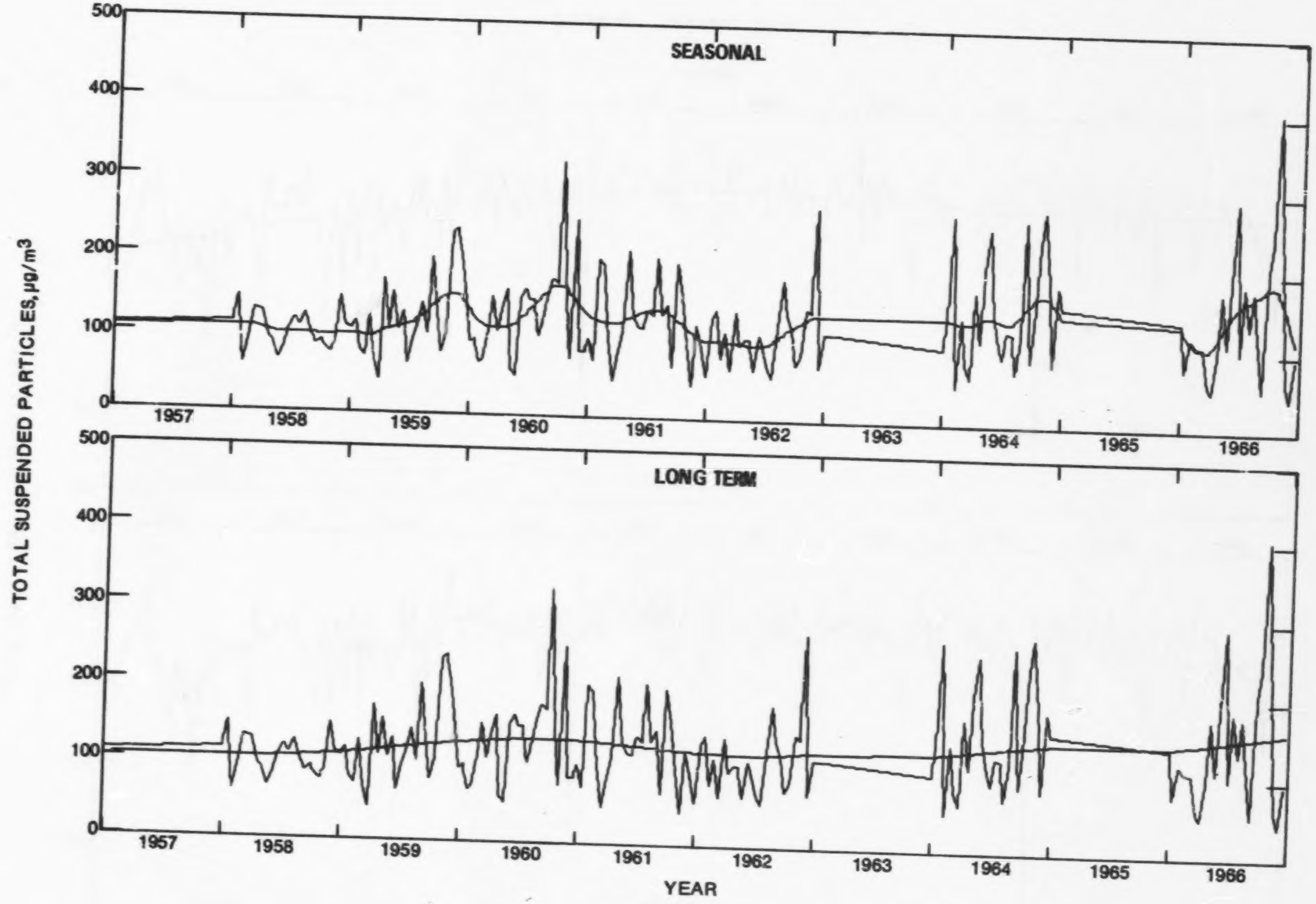

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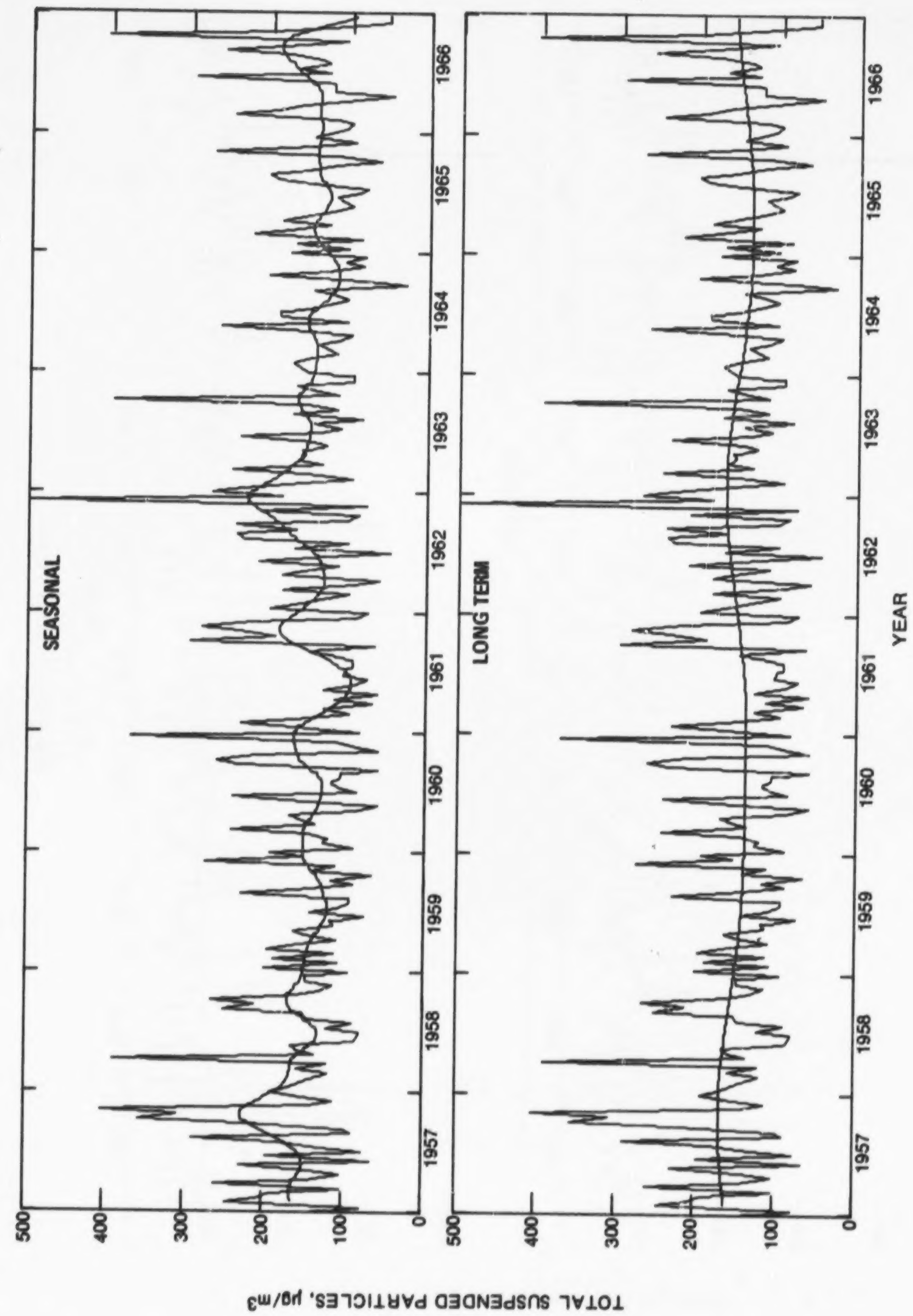

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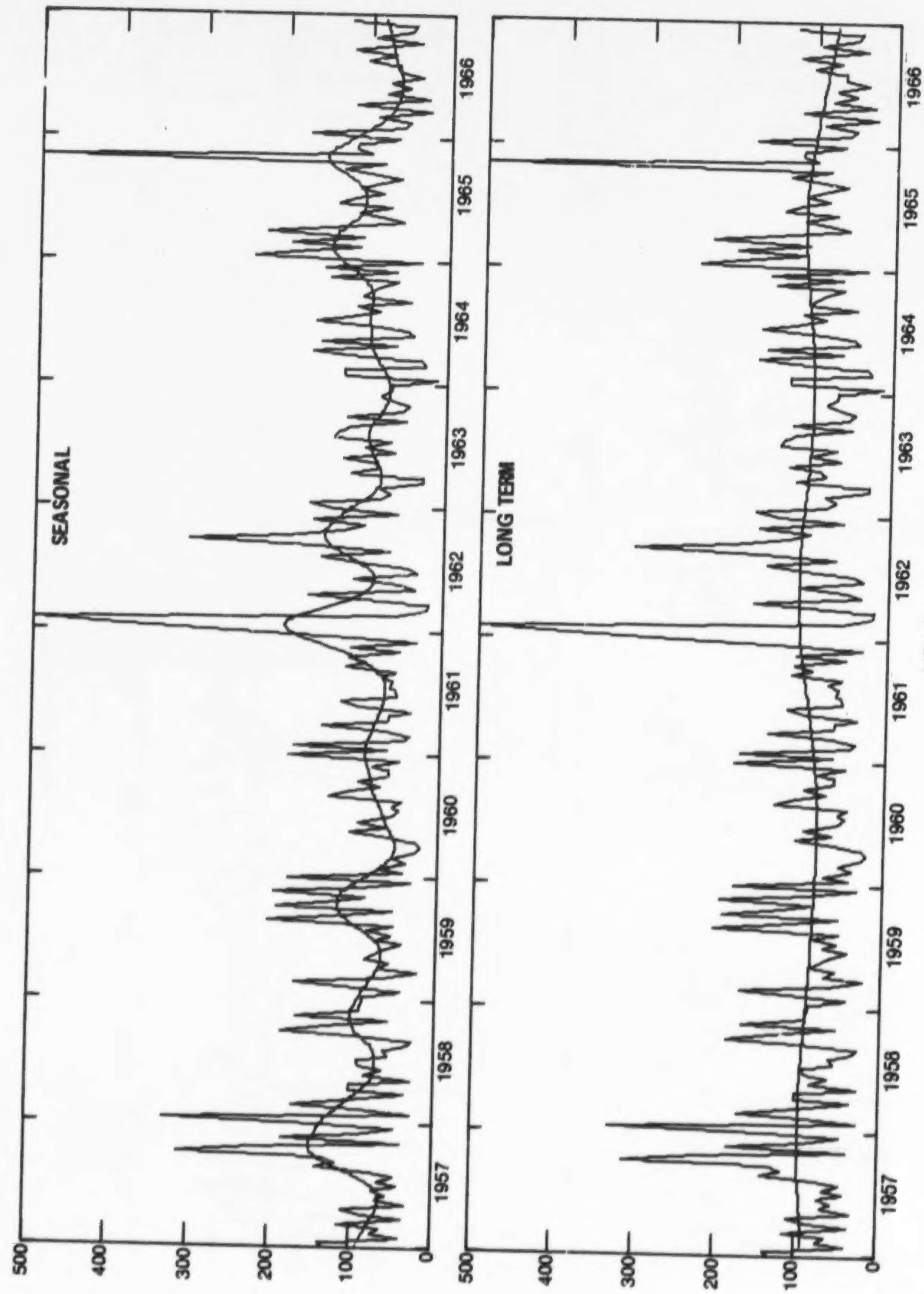

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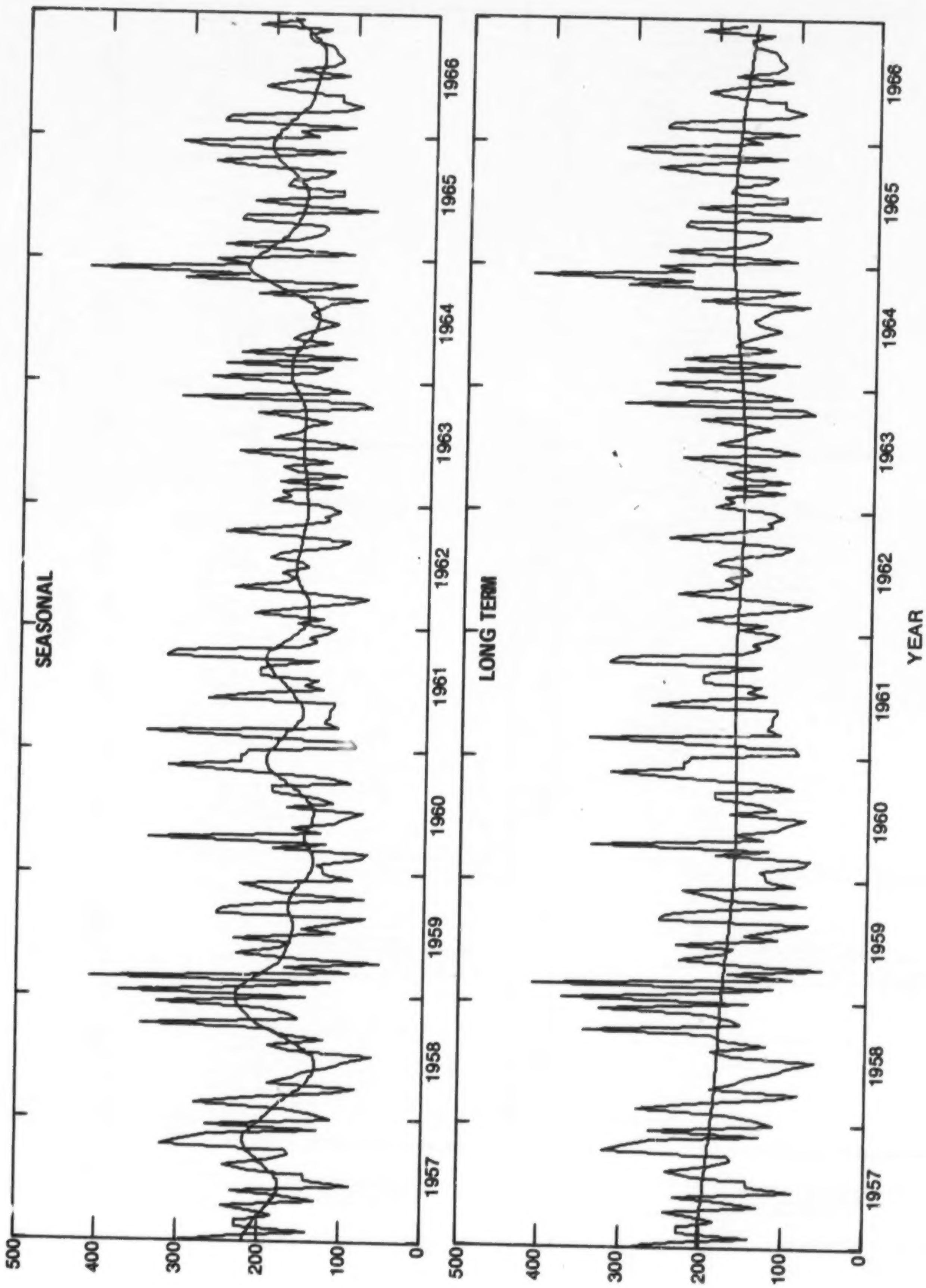

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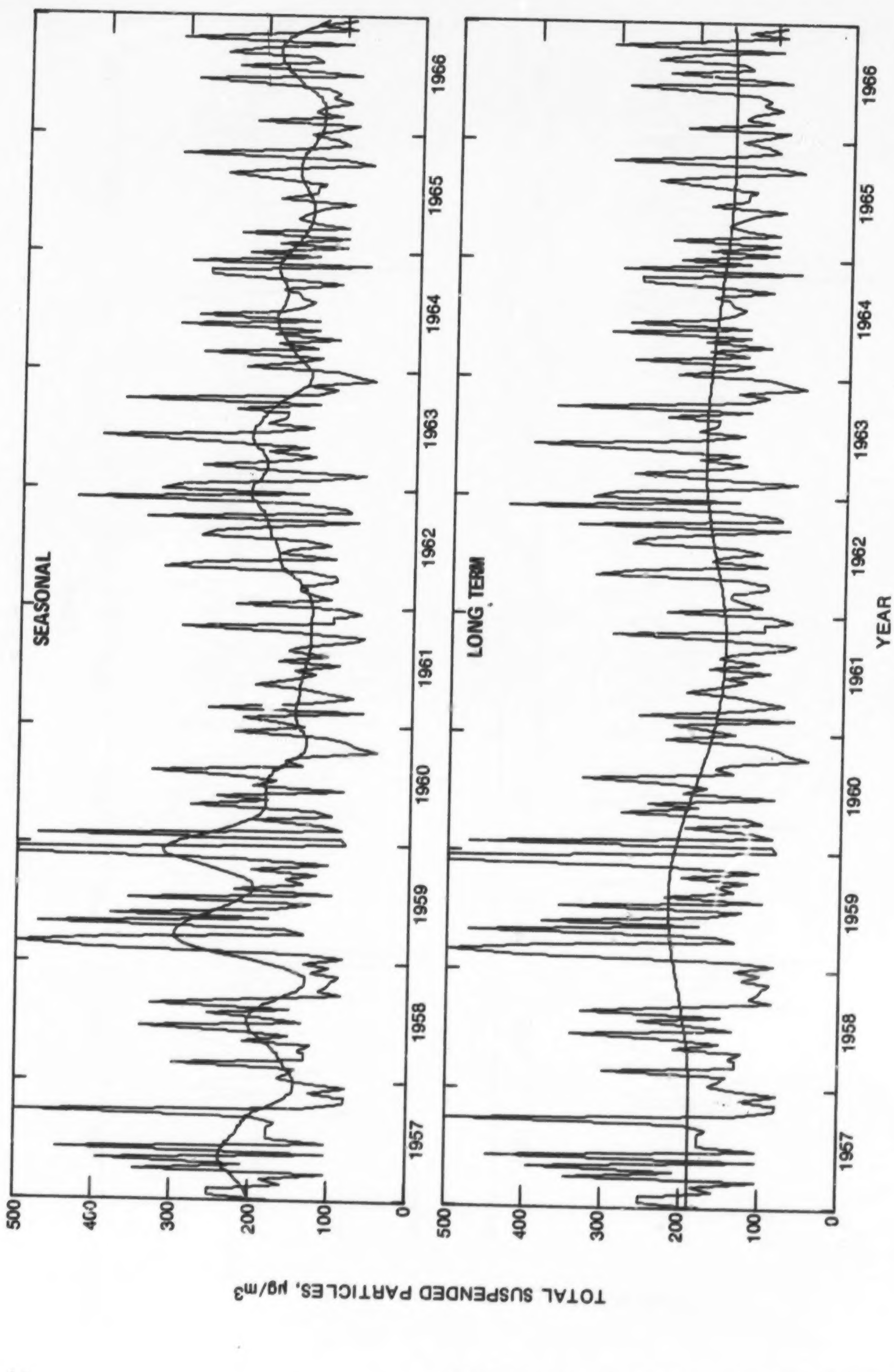


Figure 46. Pittsburgh, Pennsylvania.

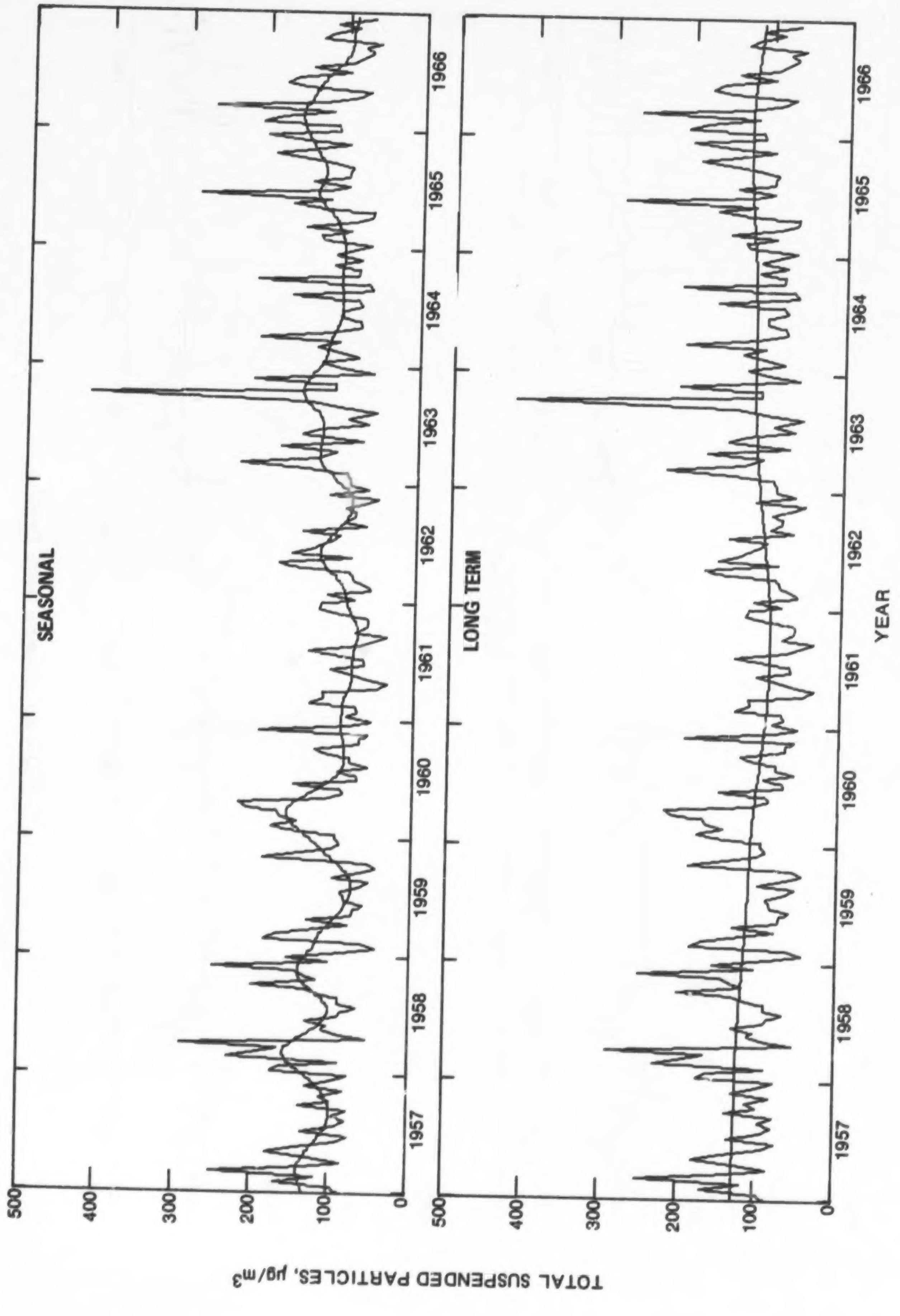


Figure 47. Providence, Rhode Island.

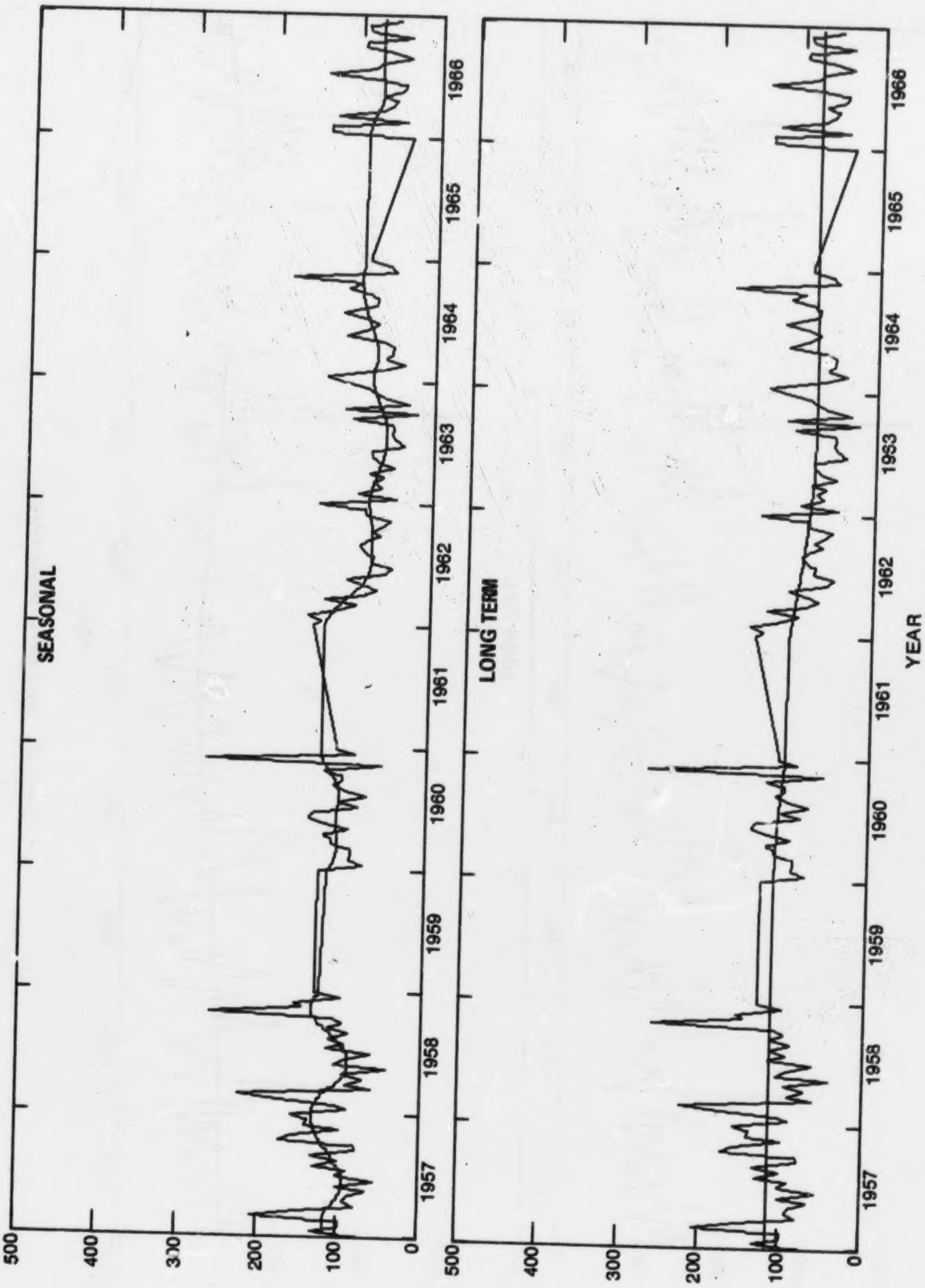


Figure 48. Columbia, South Carolina.

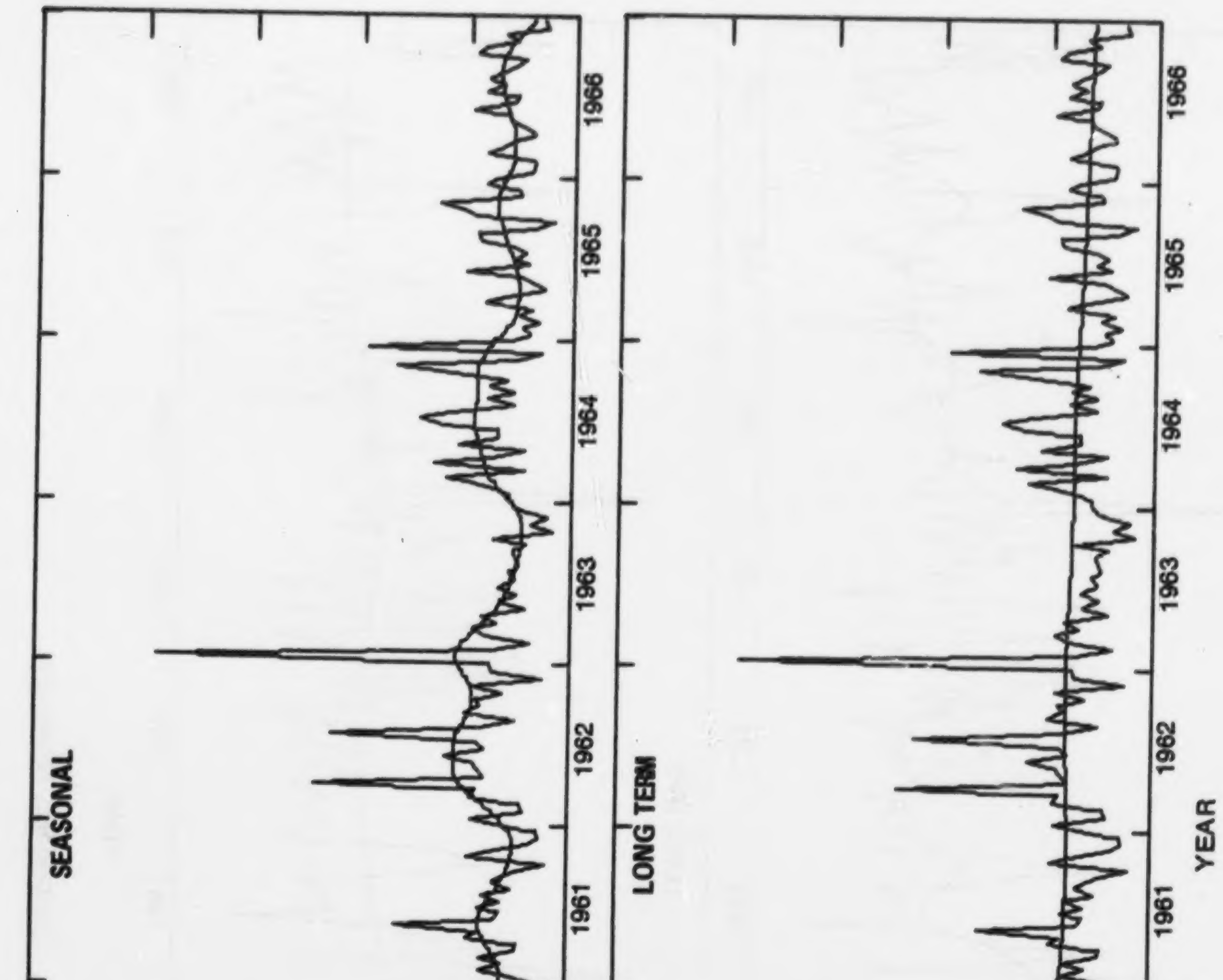


Figure 49. Sioux Falls, South Dakota.

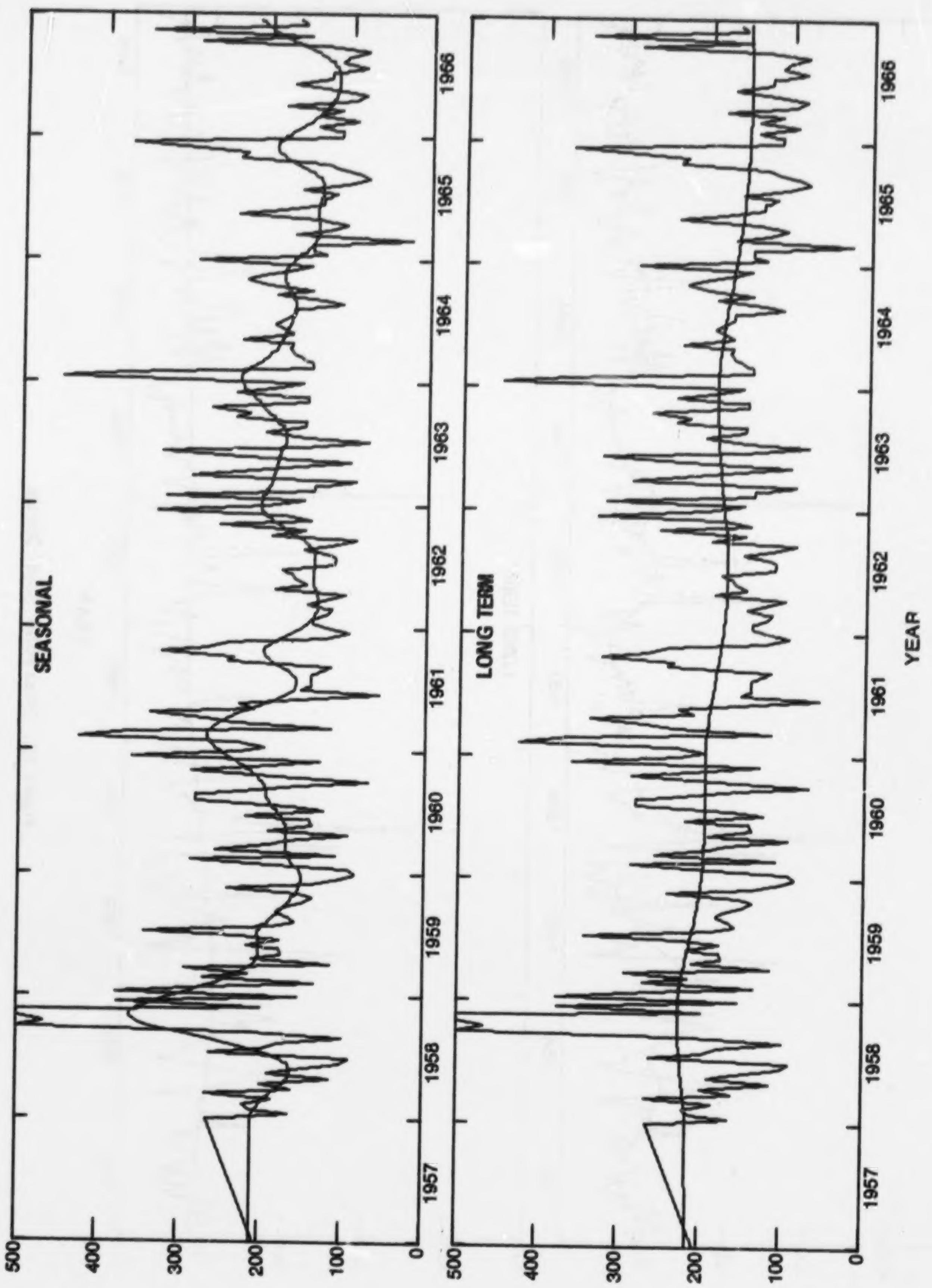


Figure 50. Chattanooga, Tennessee.

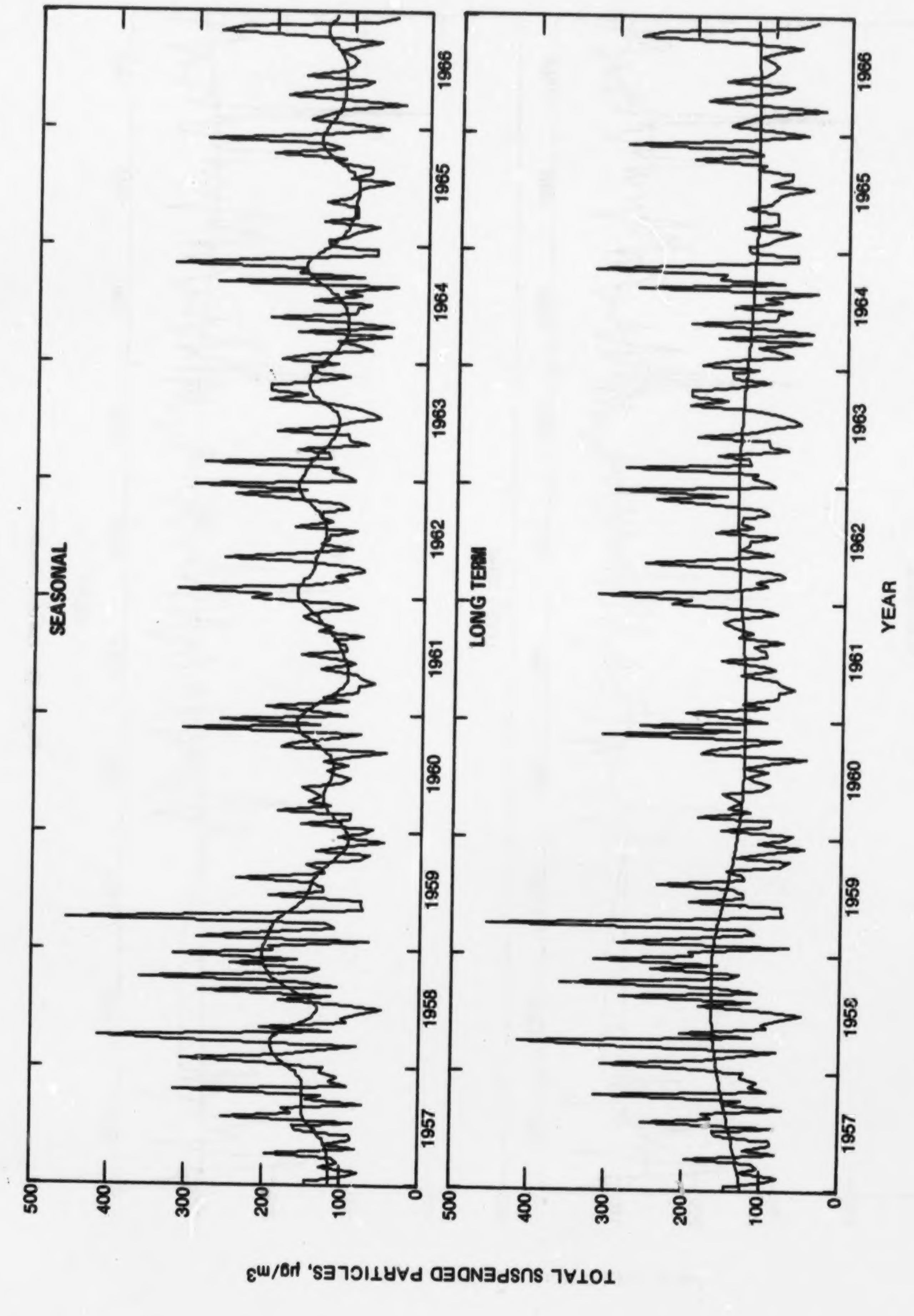


Figure 51. Nashville, Tennessee.

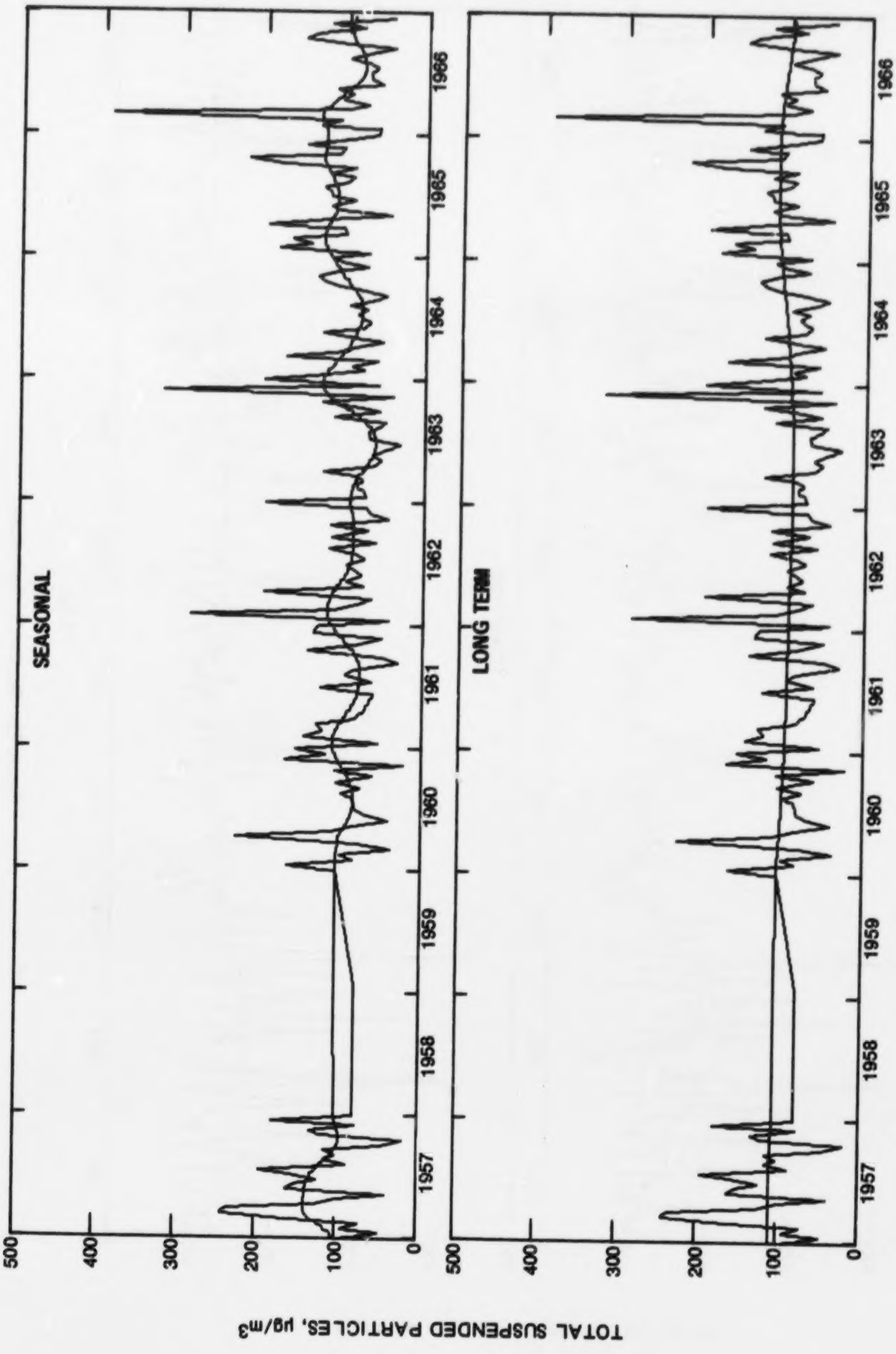


Figure 52. Dallas, Texas.

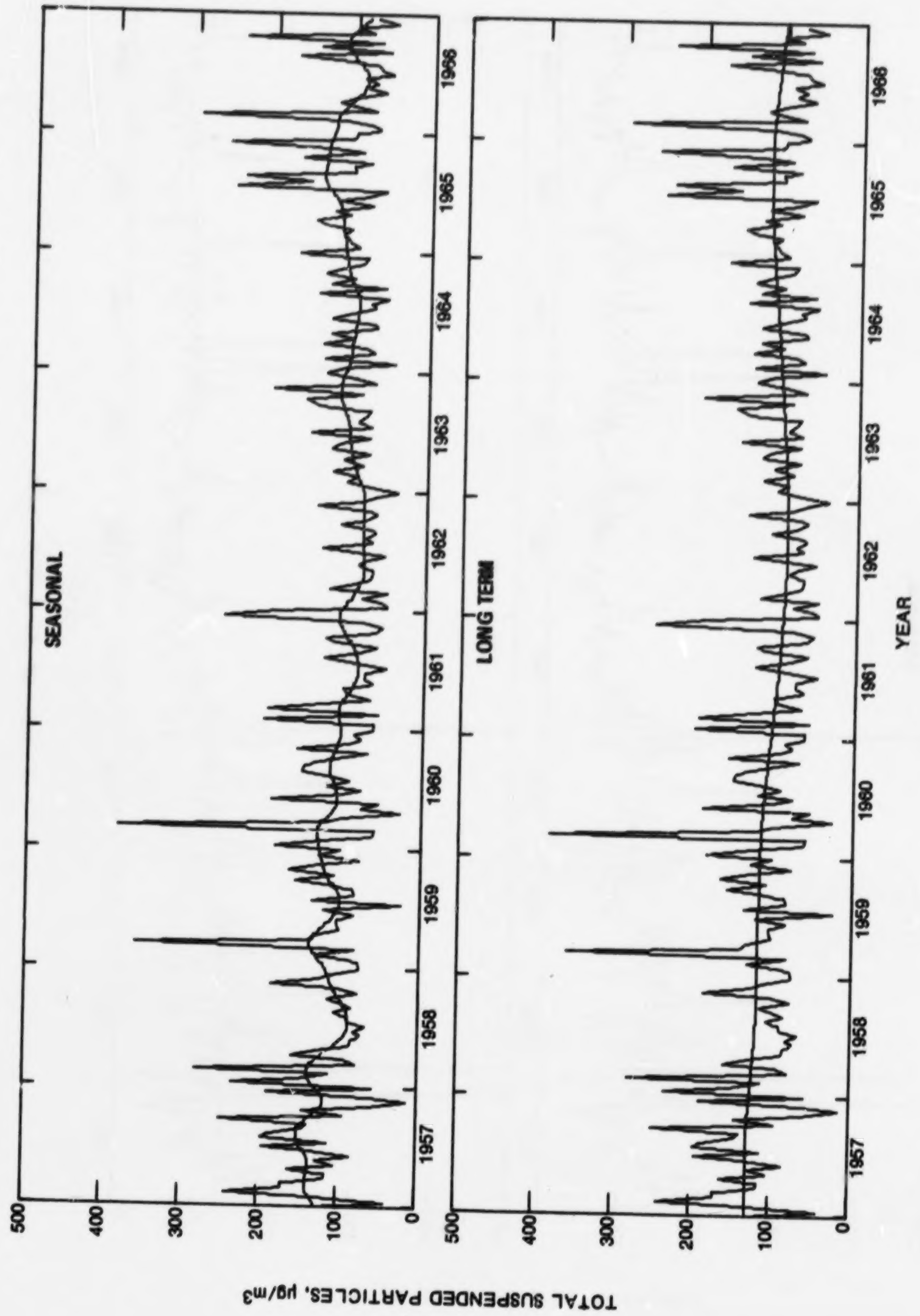


Figure 53. Houston, Texas.

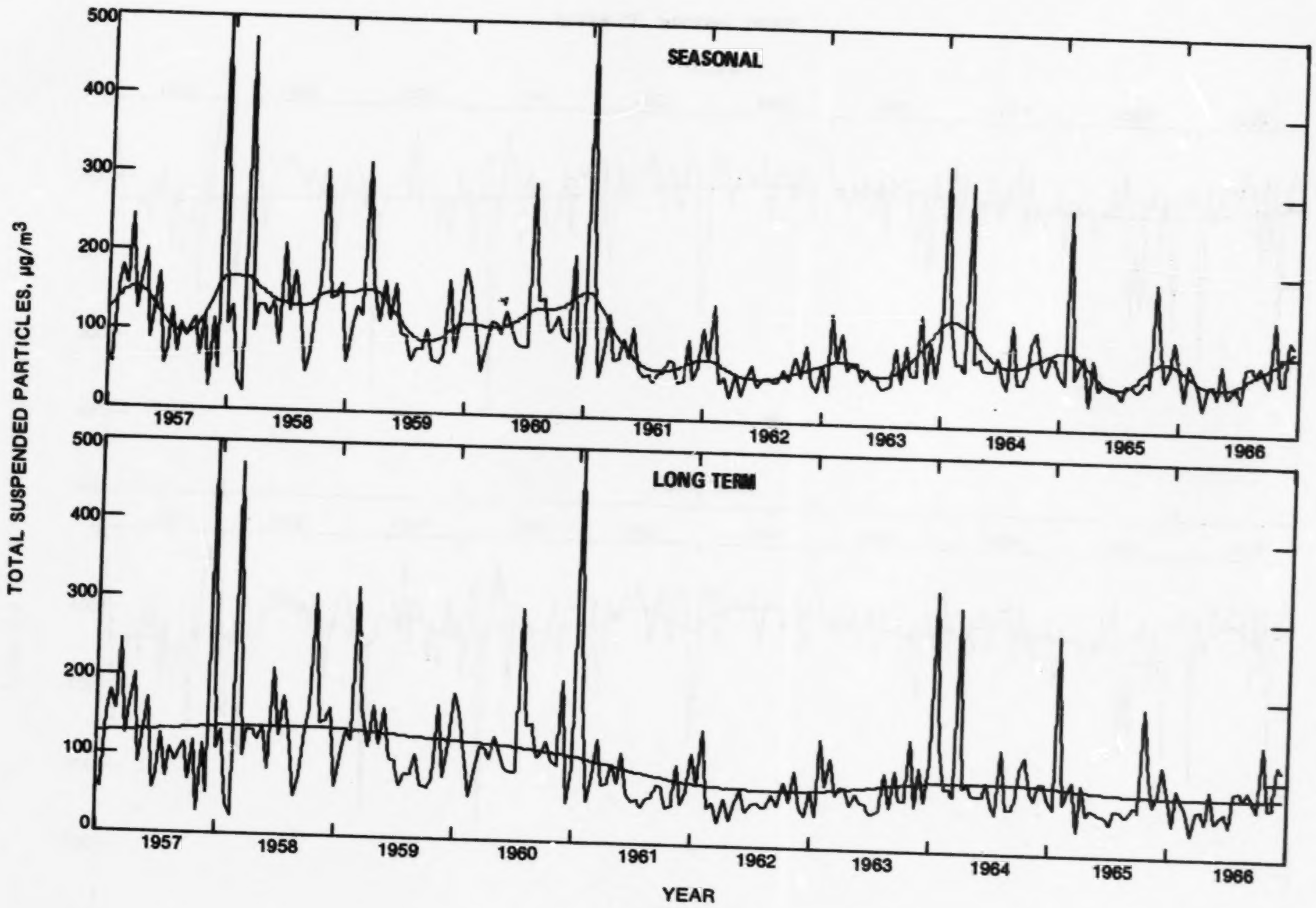


Figure 54. San Antonio, Texas.

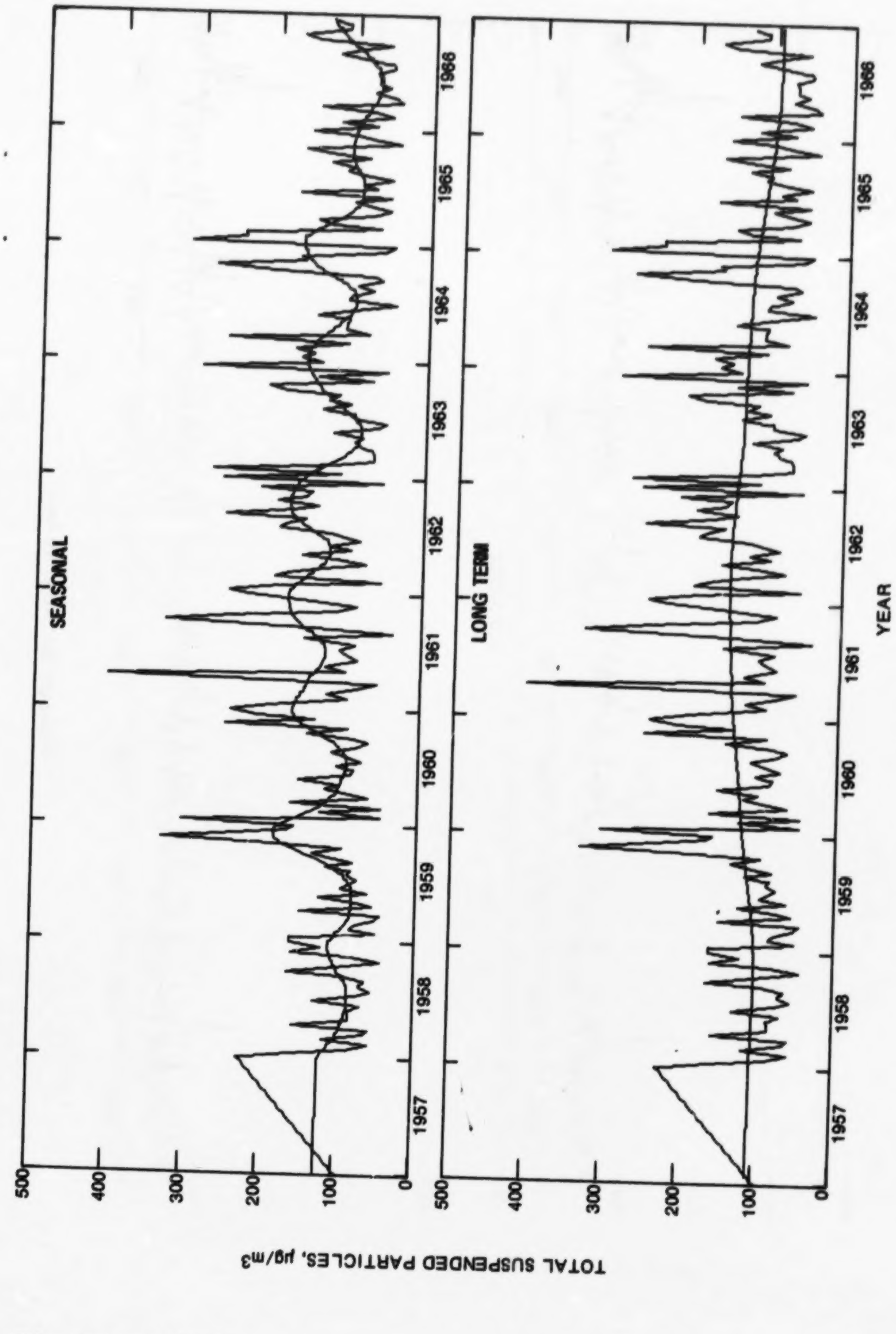


Figure 55. Salt Lake City, Utah.

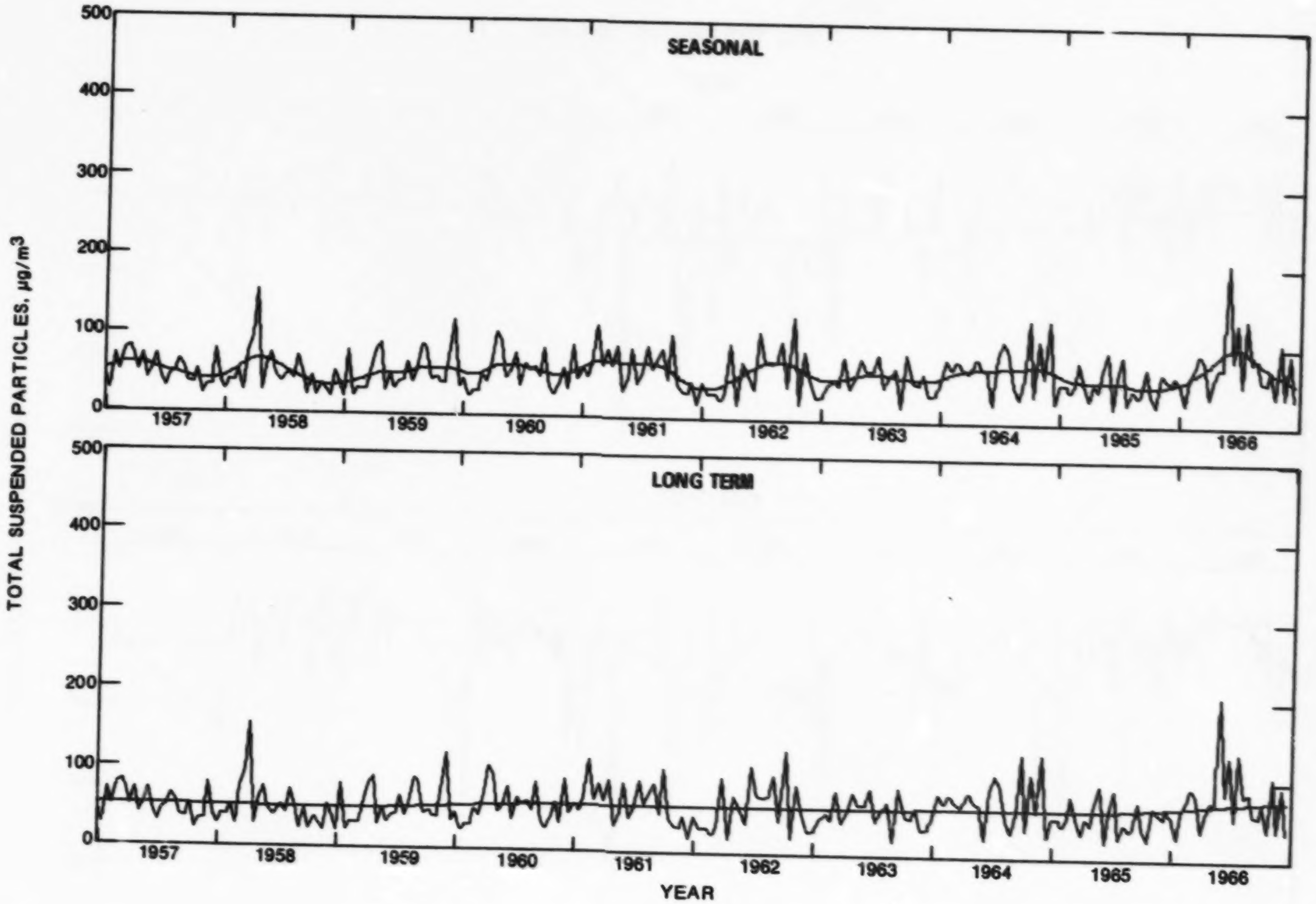


Figure 56. Burlington, Vermont.

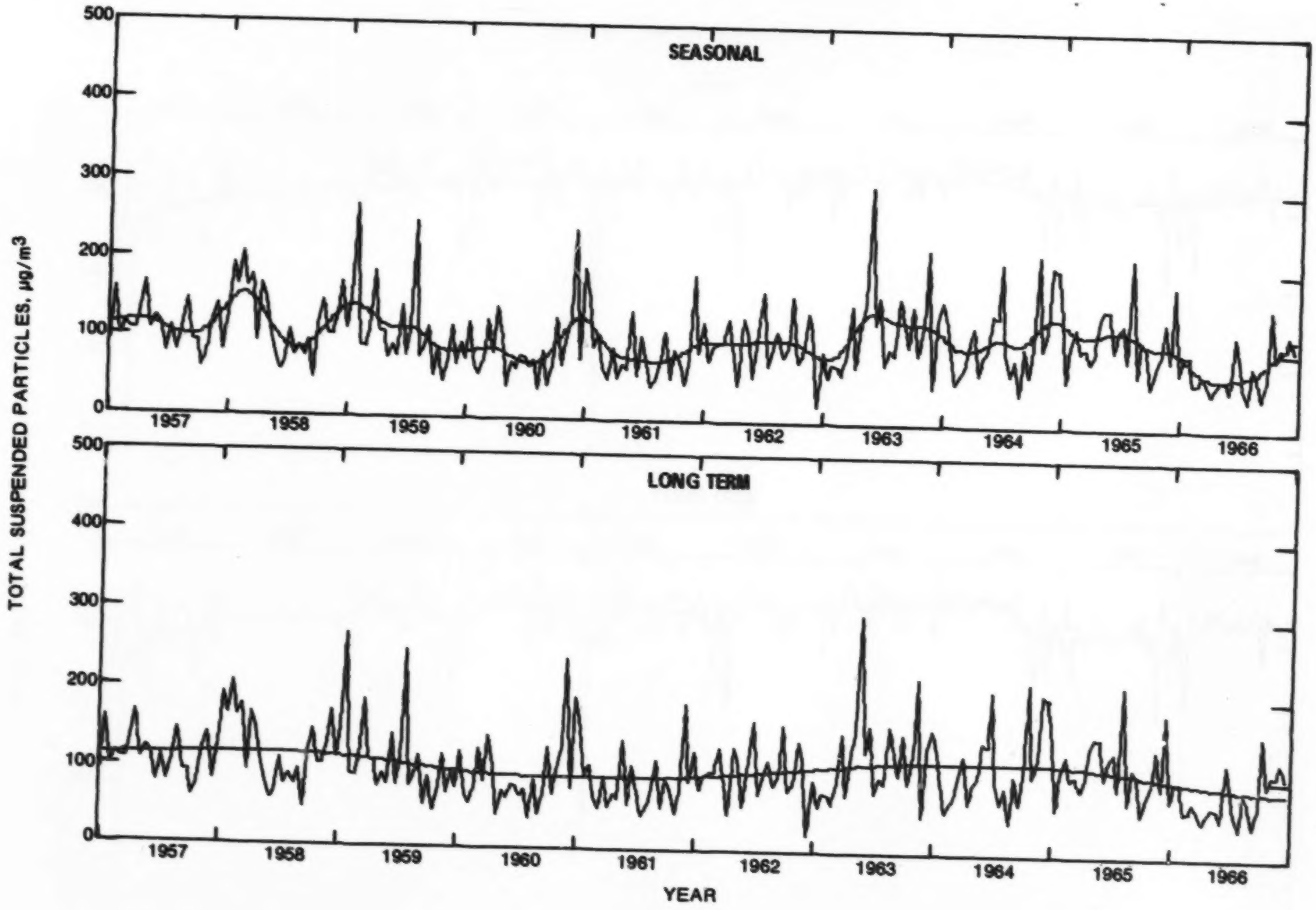
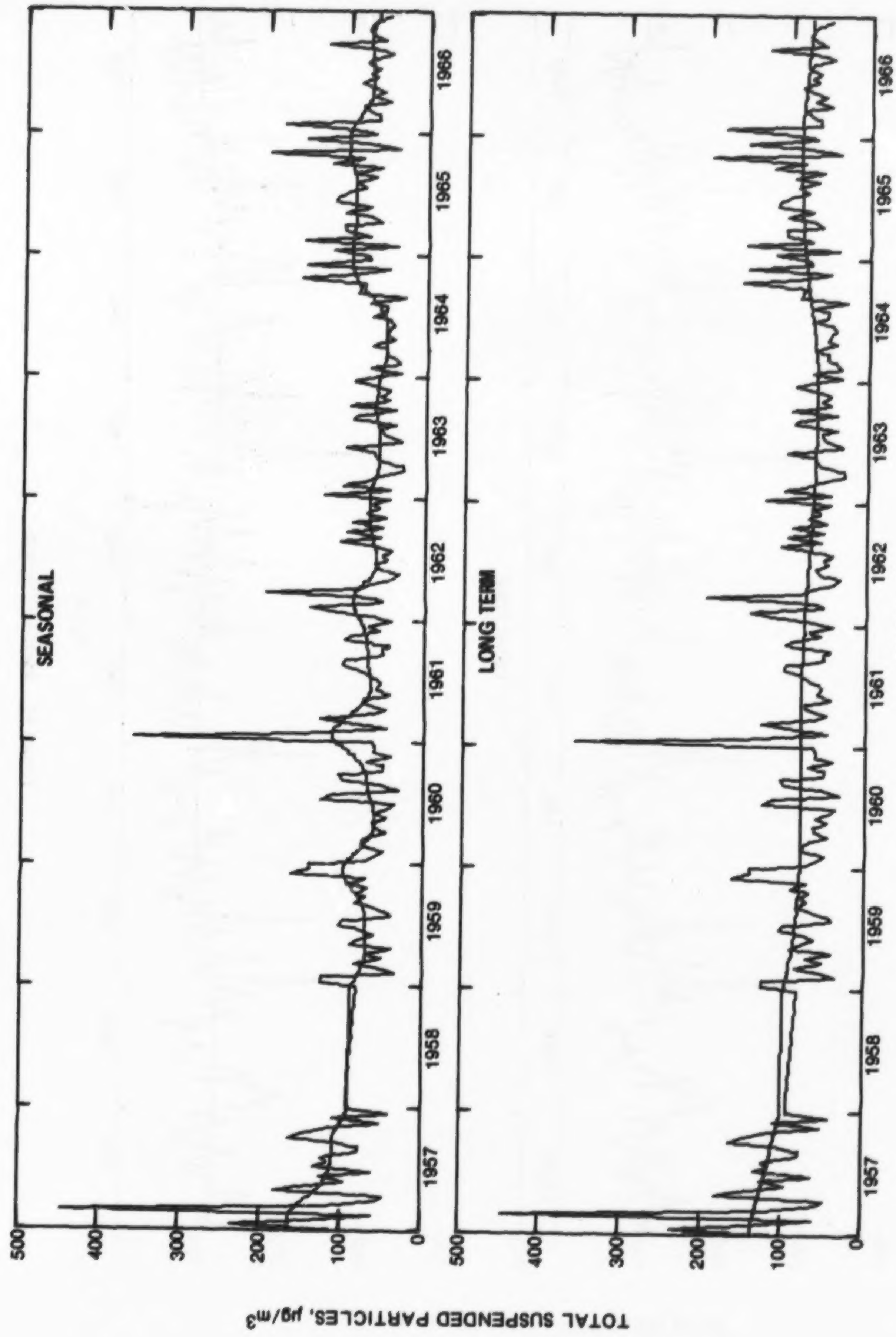


Figure 57. Norfolk, Virginia.



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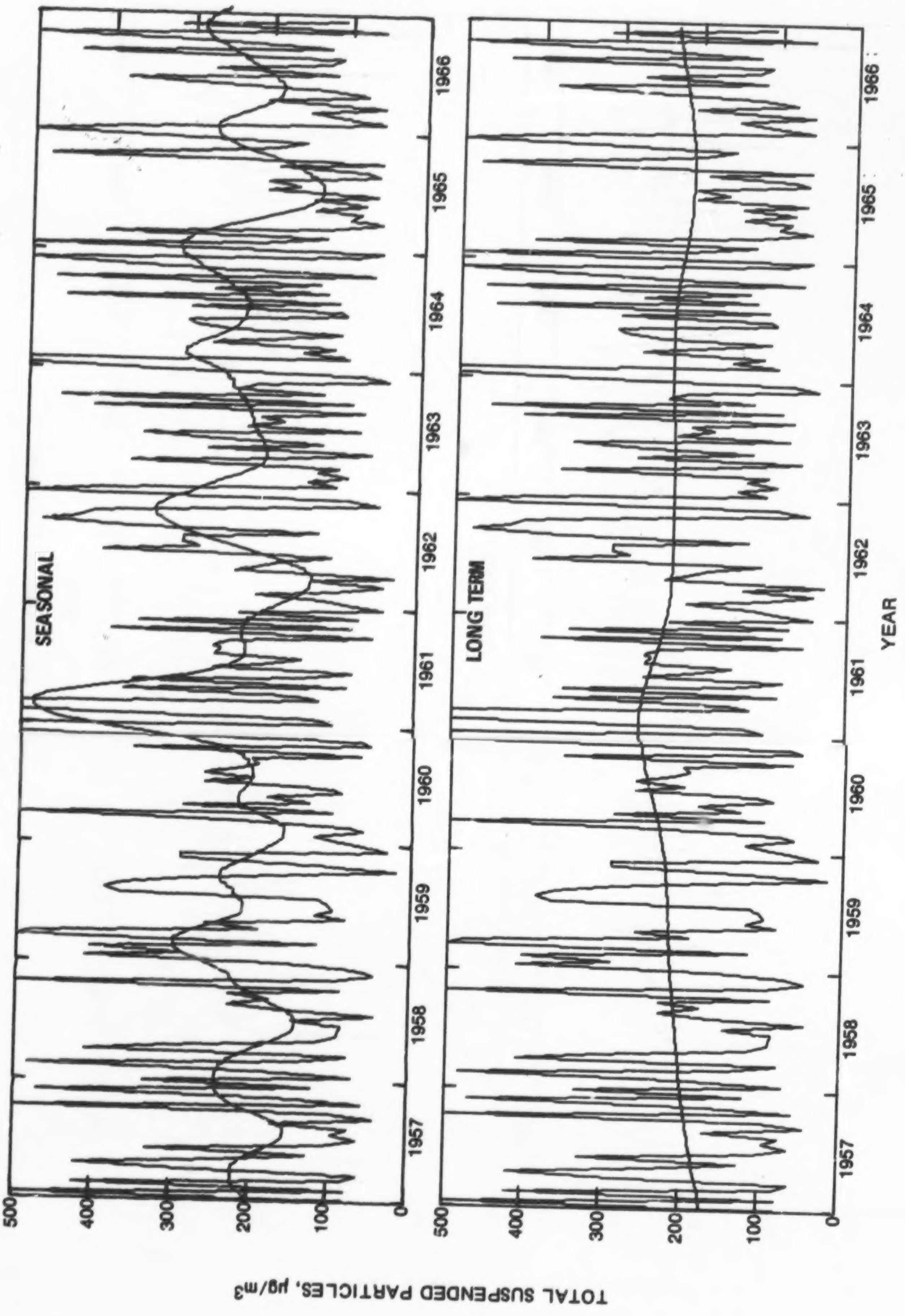

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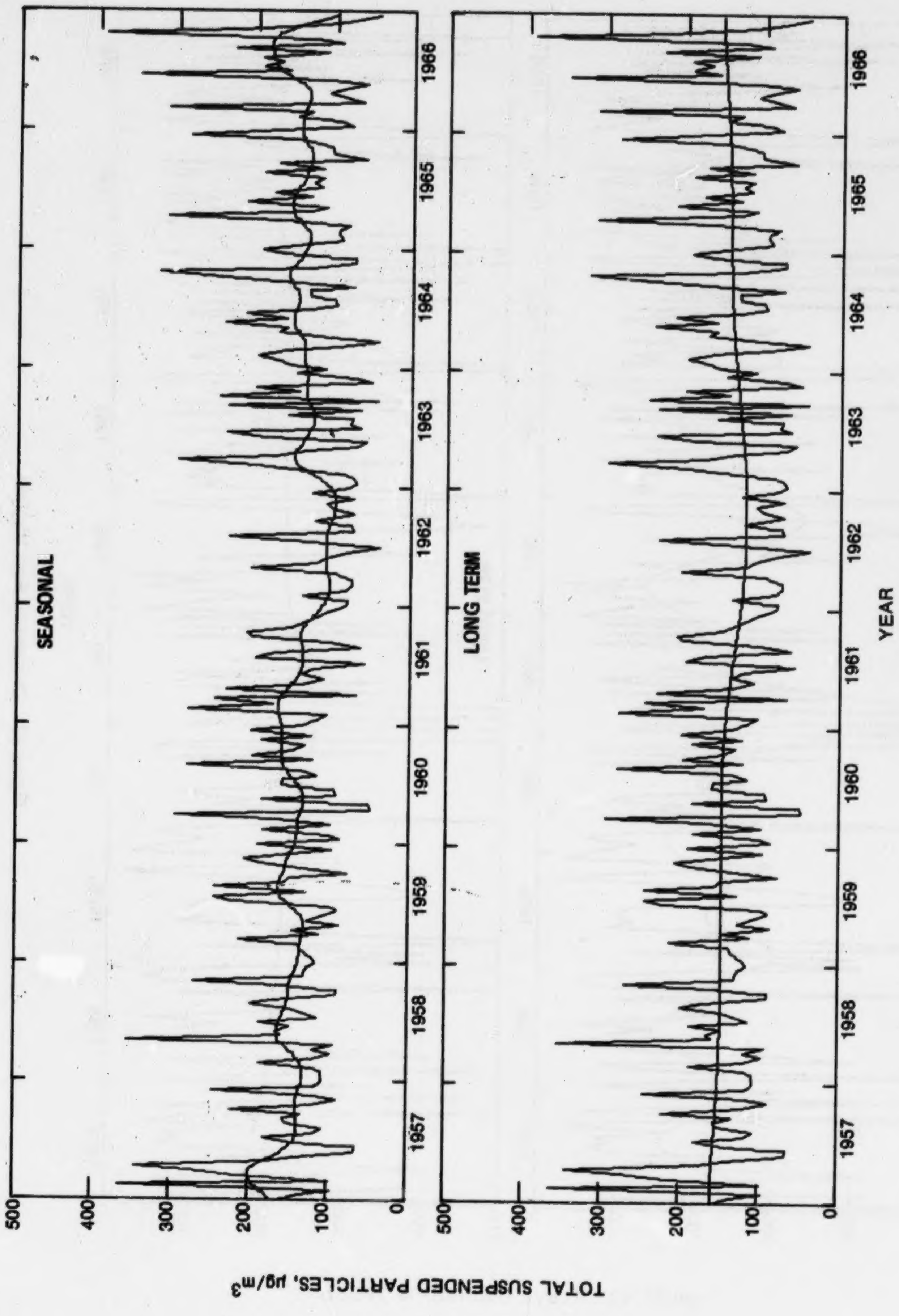
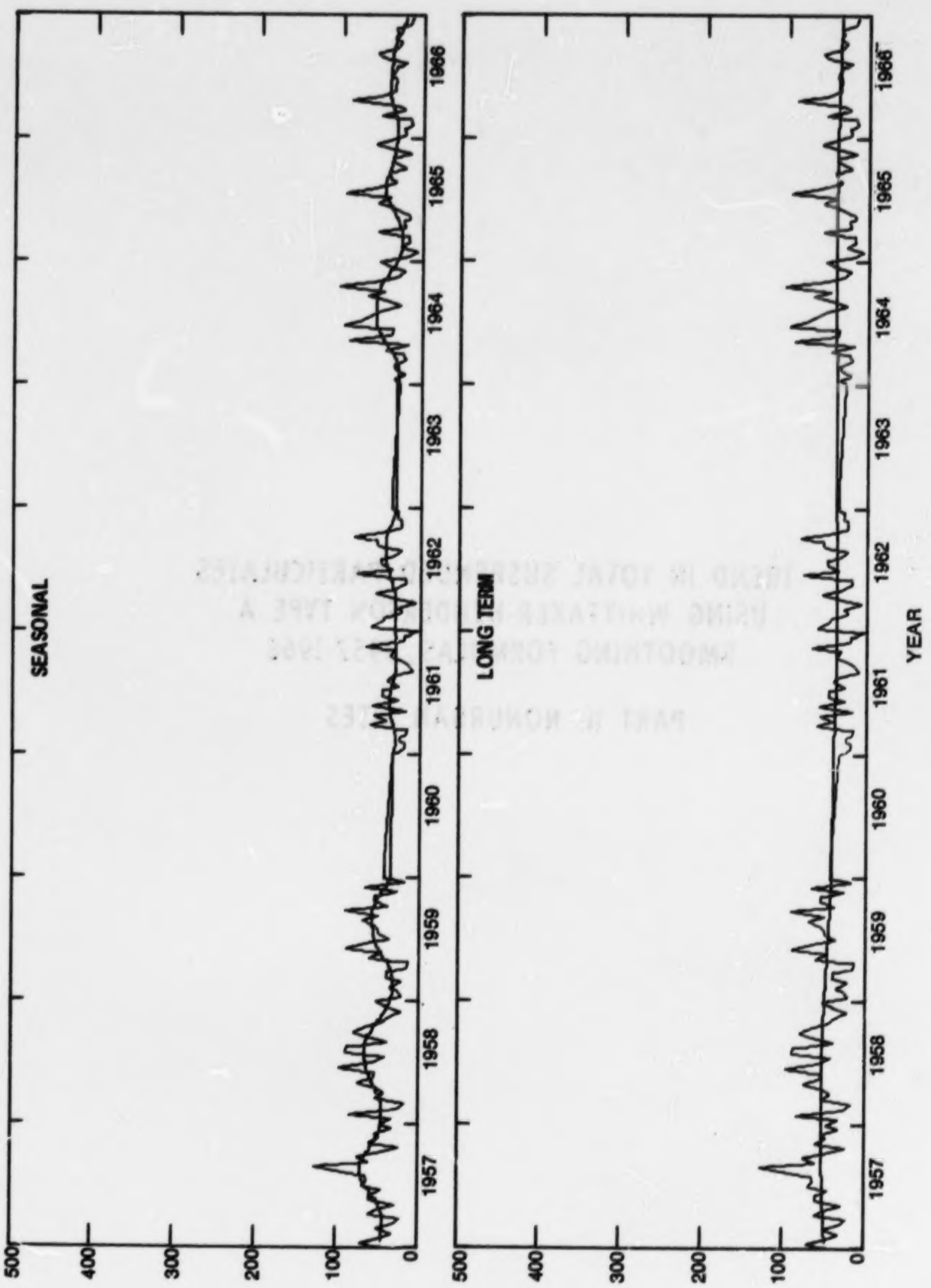


Figure 60. Milwaukee, Wisconsin.

TREND IN TOTAL SUSPENDED PARTICULATES USING WHITTAKER-HENDERSON TYPE A SMOOTHING FORMULAS, 1957-1966

PART II. NONURBAN SITES



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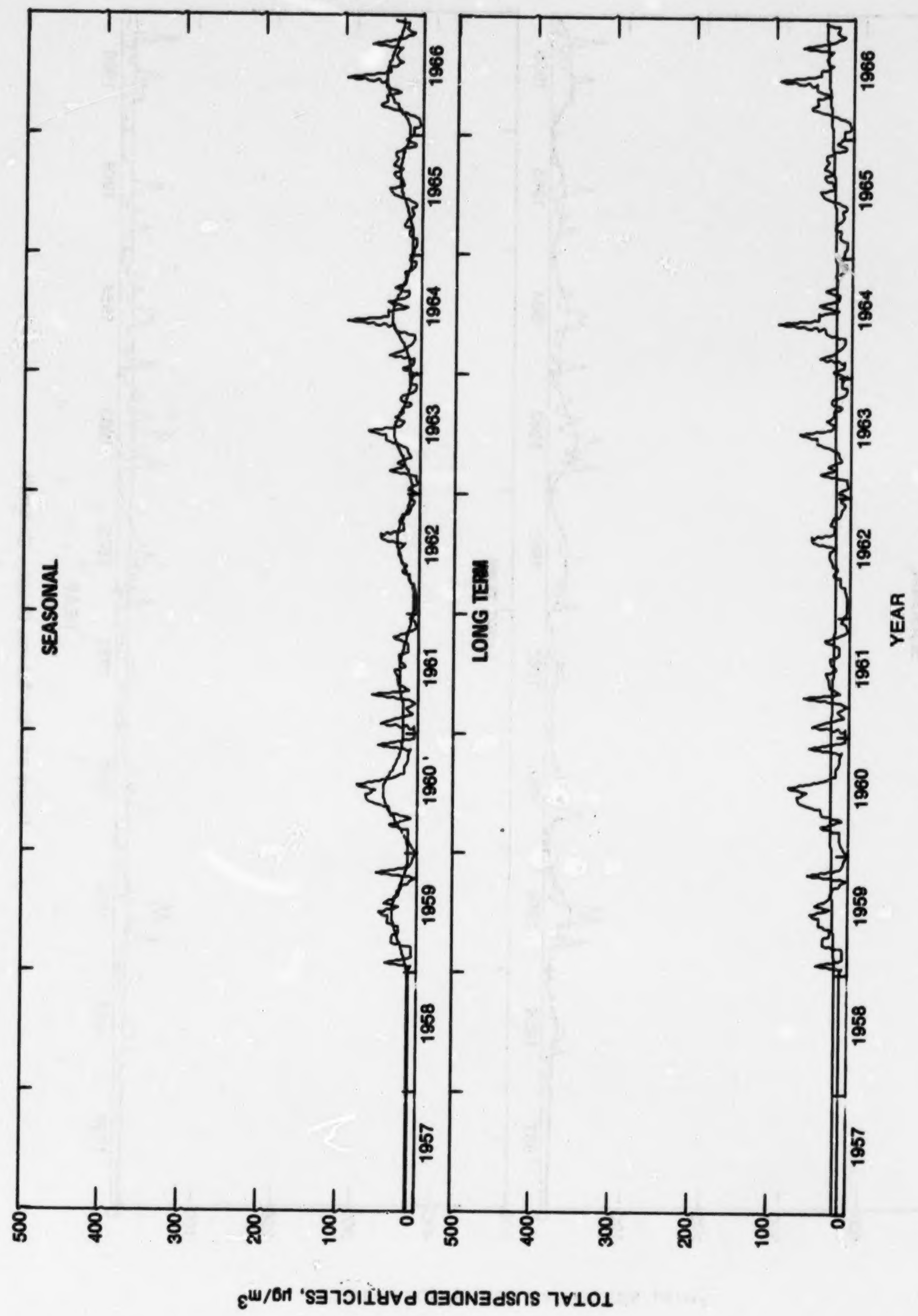


Figure 62. Grand Canyon Park, Arizona.

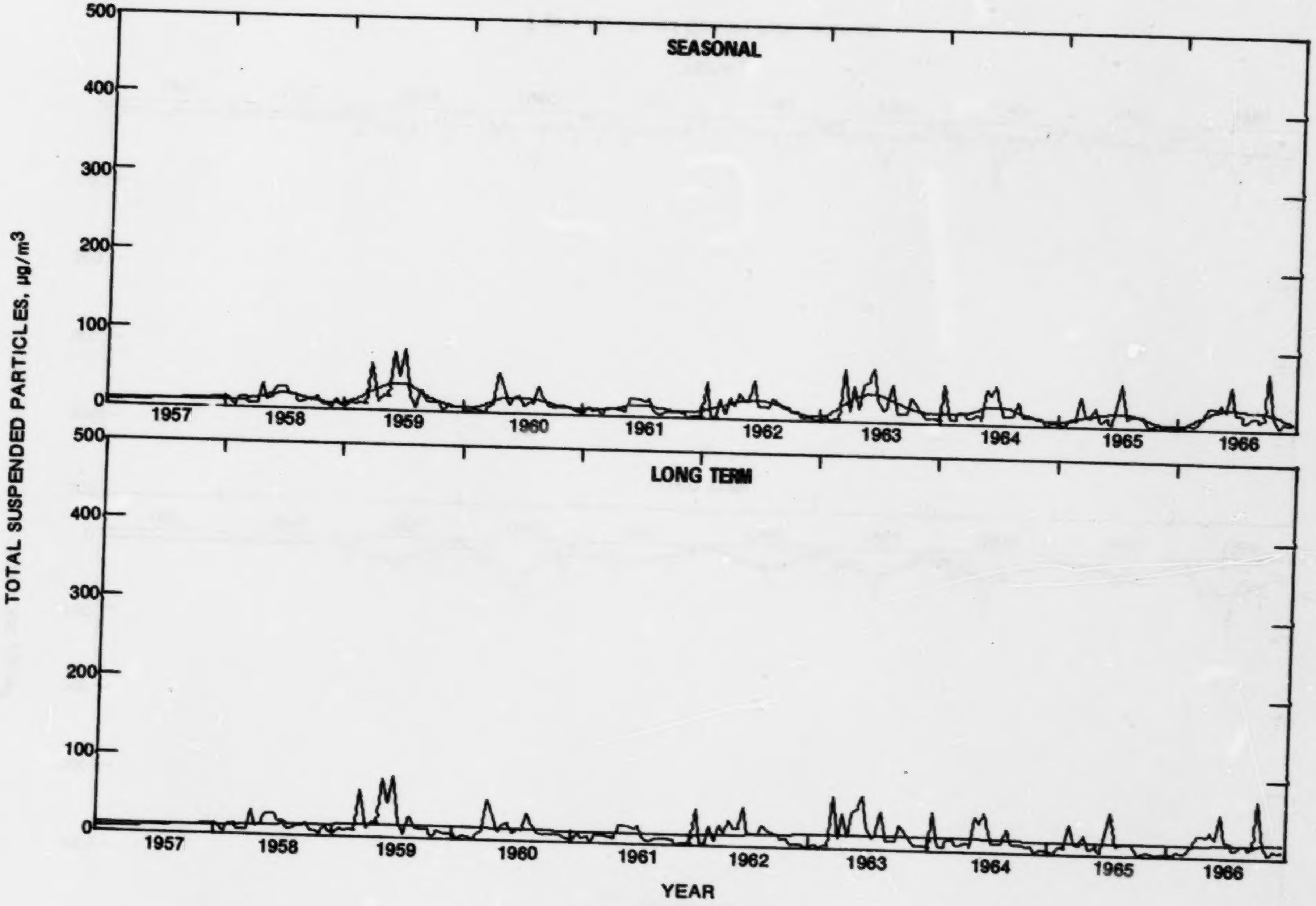


Figure 63. Montezuma County, Colorado.

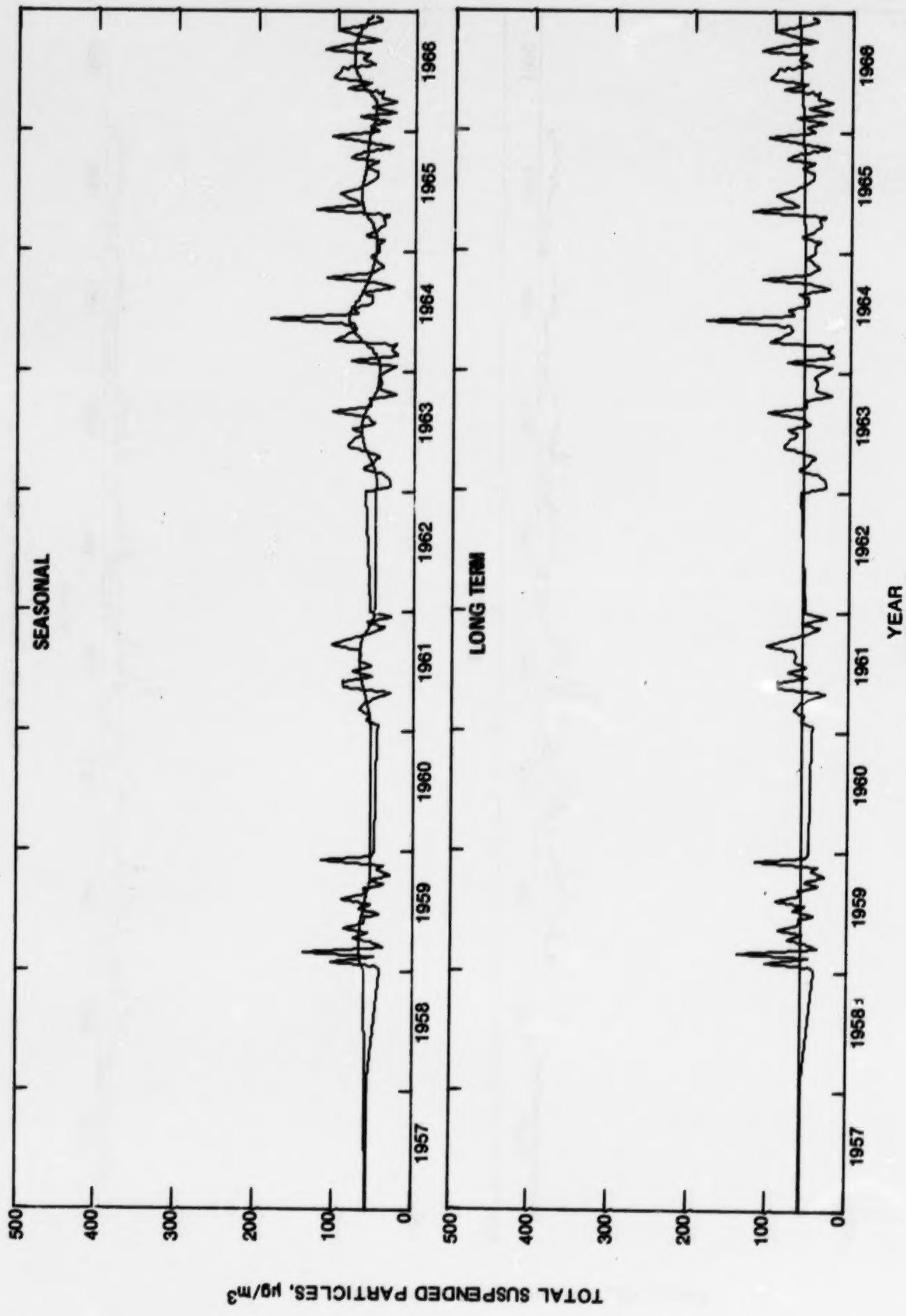


Figure 64. Kent County, Delaware.

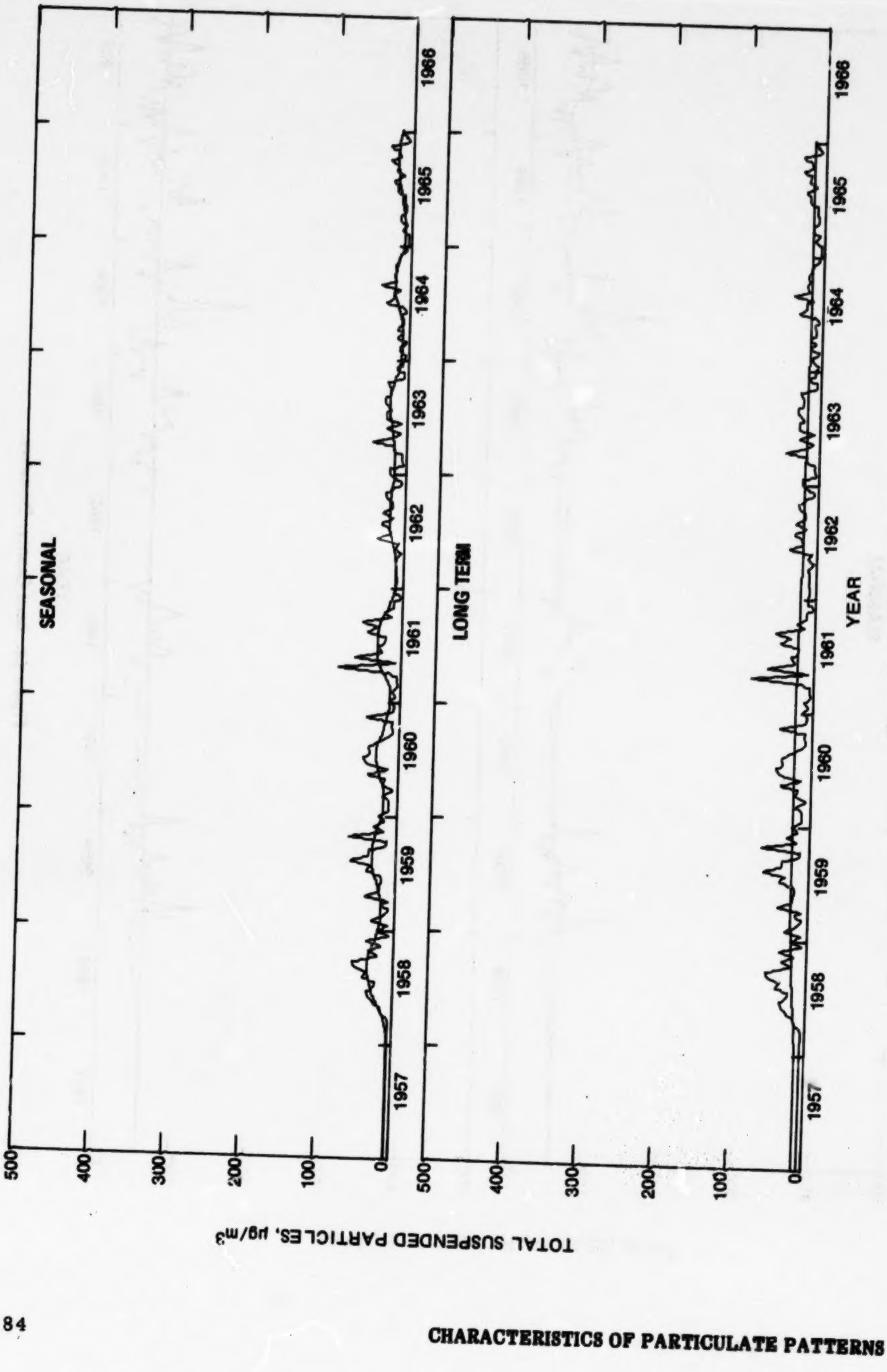
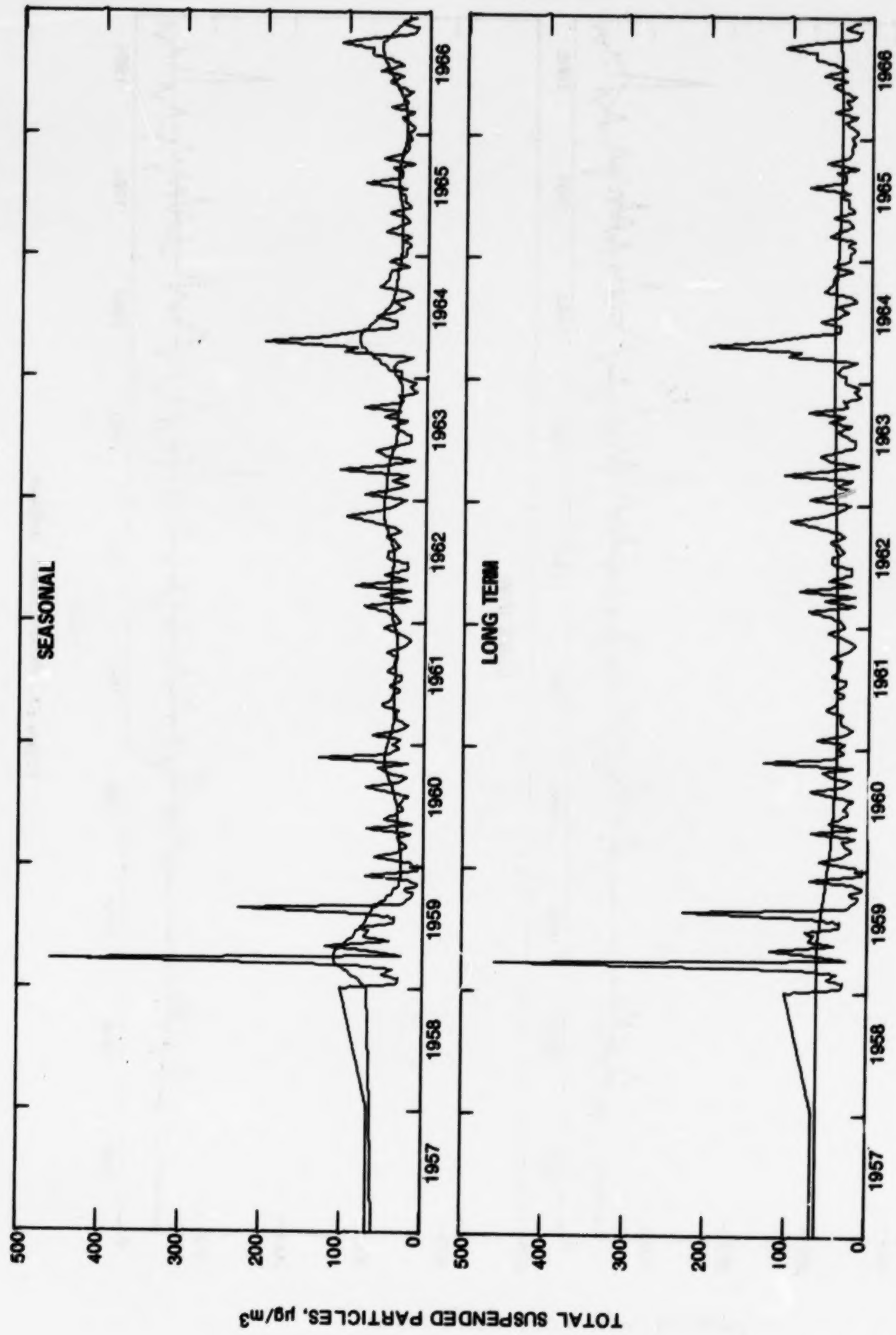


Figure 65. Butte County, Idaho.



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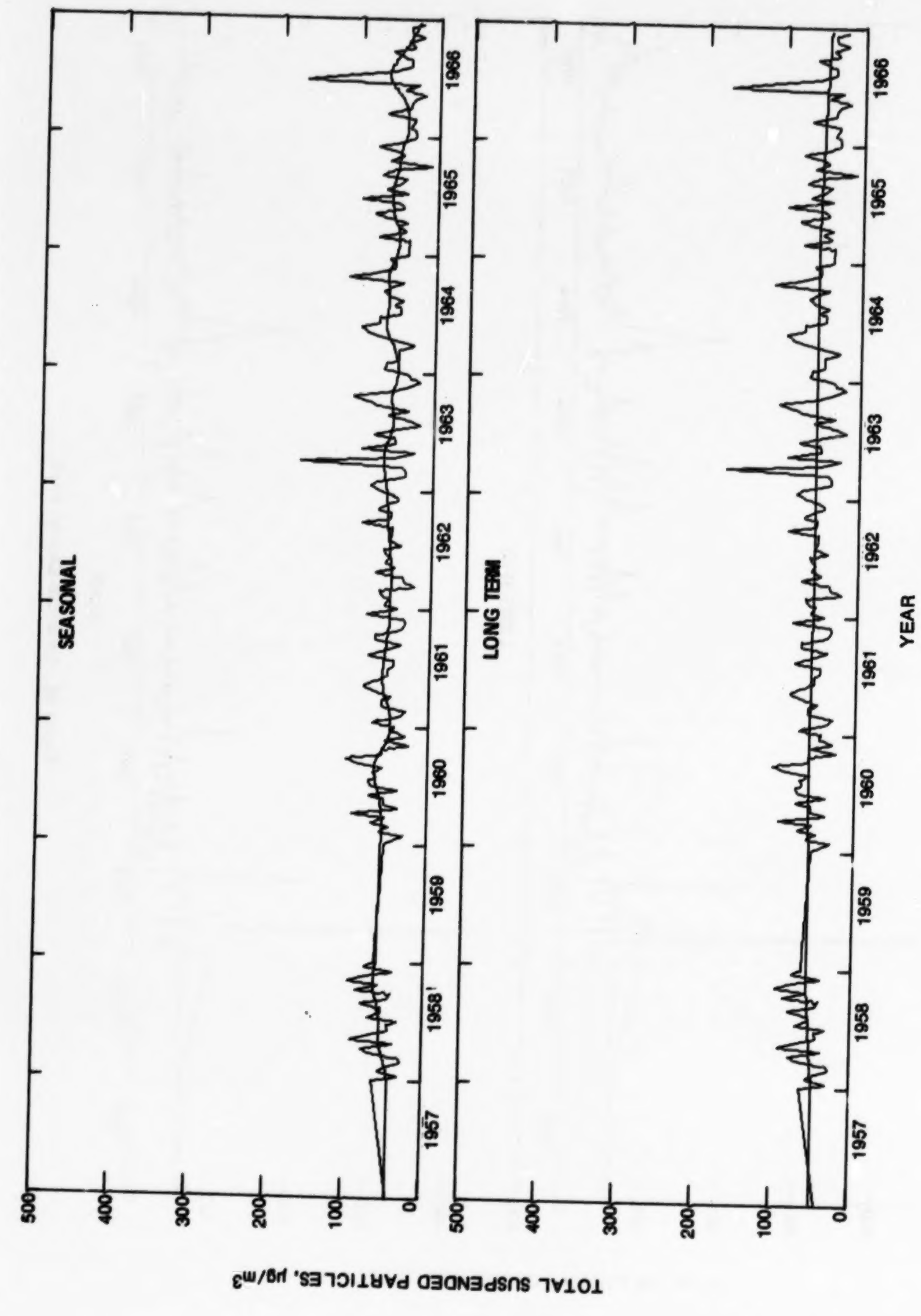

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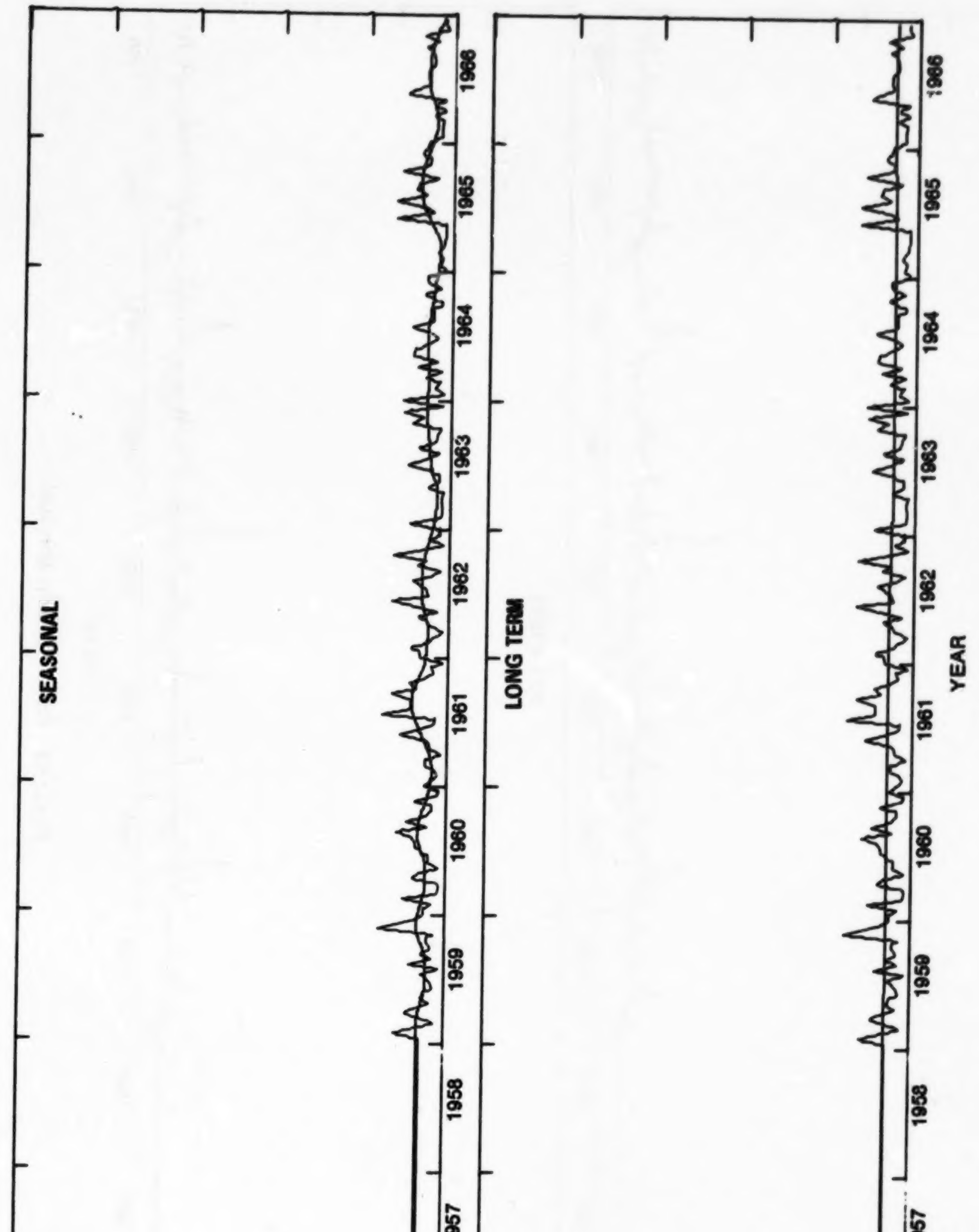
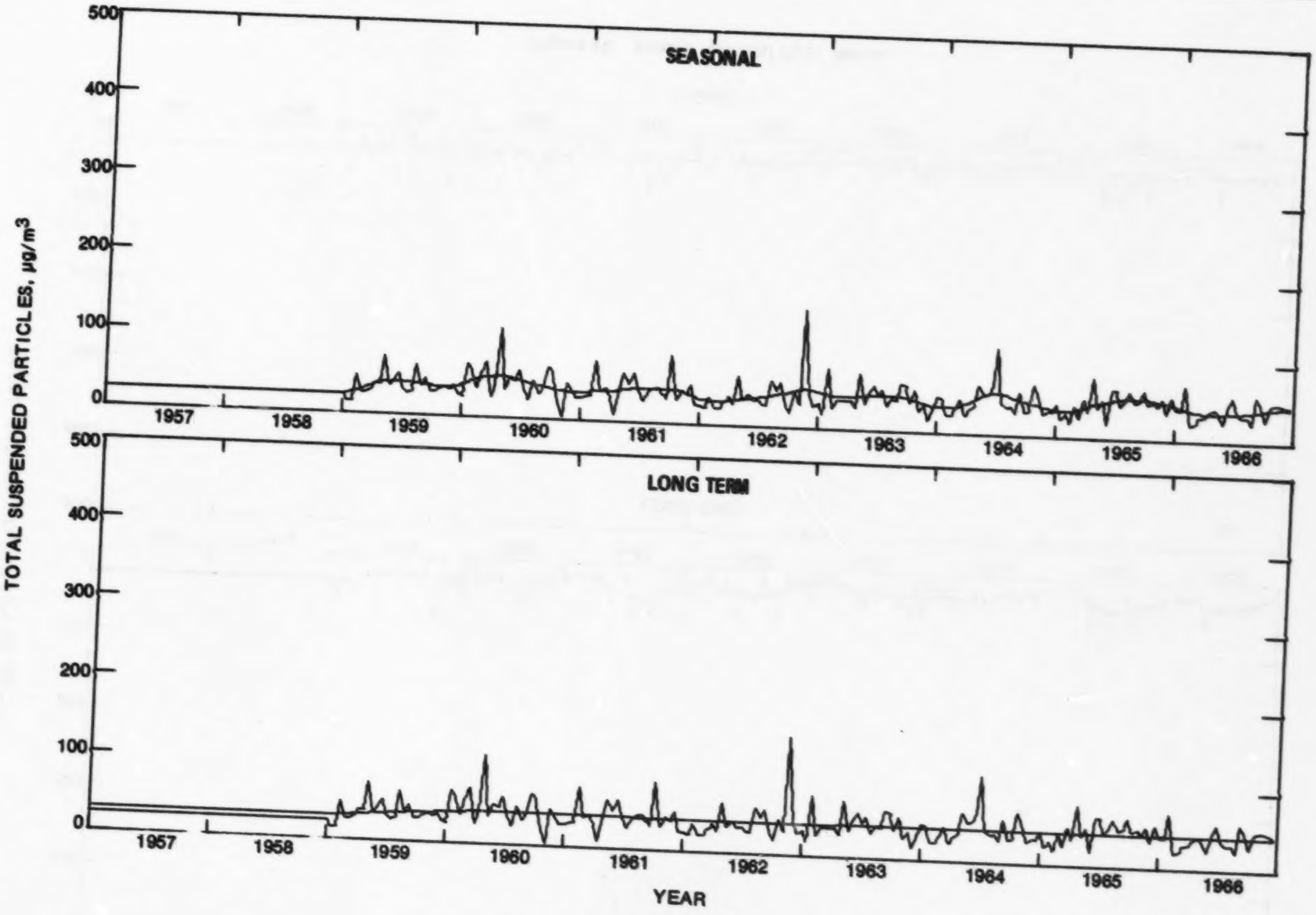


Figure 68. Acadia National Park, Maine.



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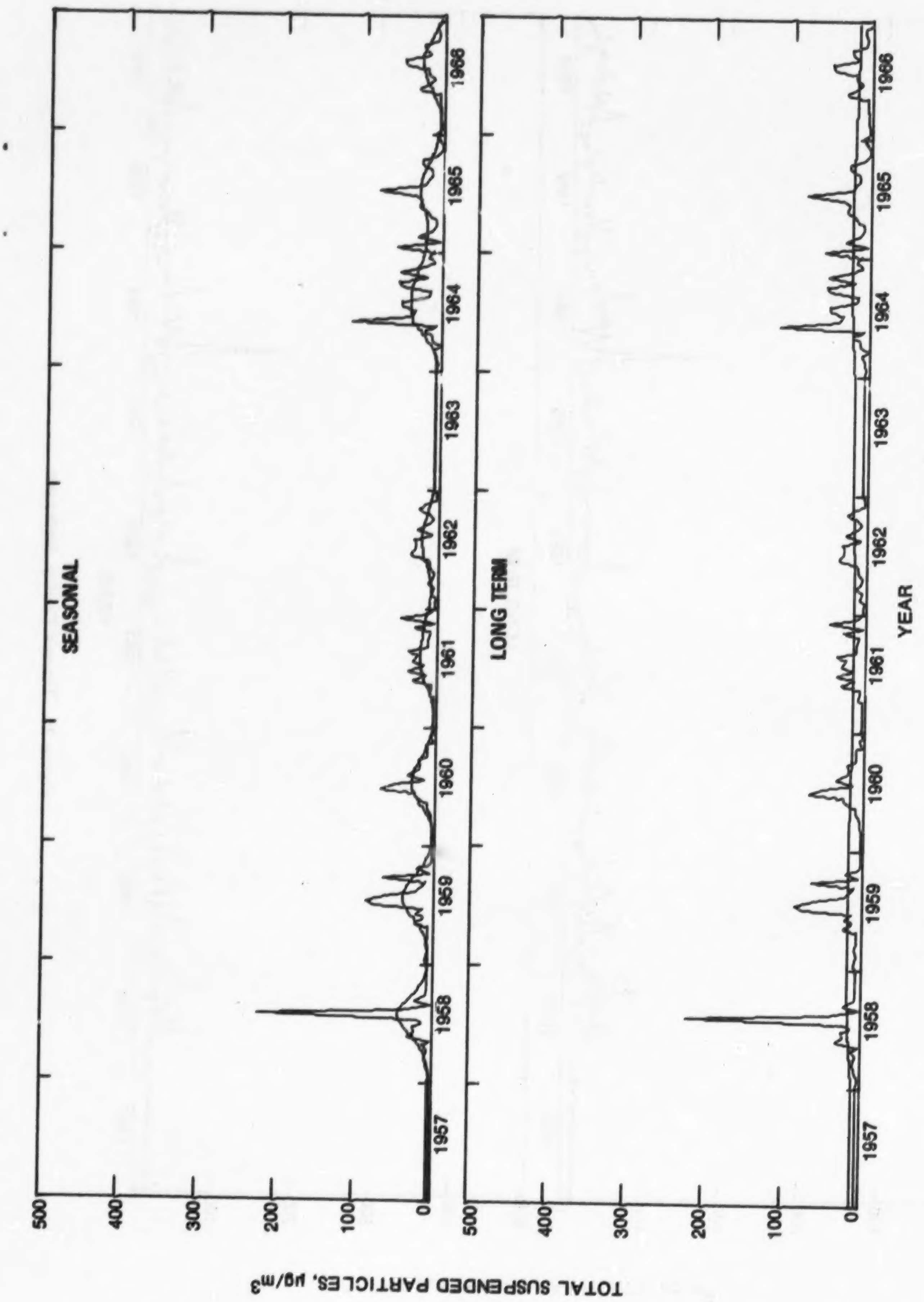

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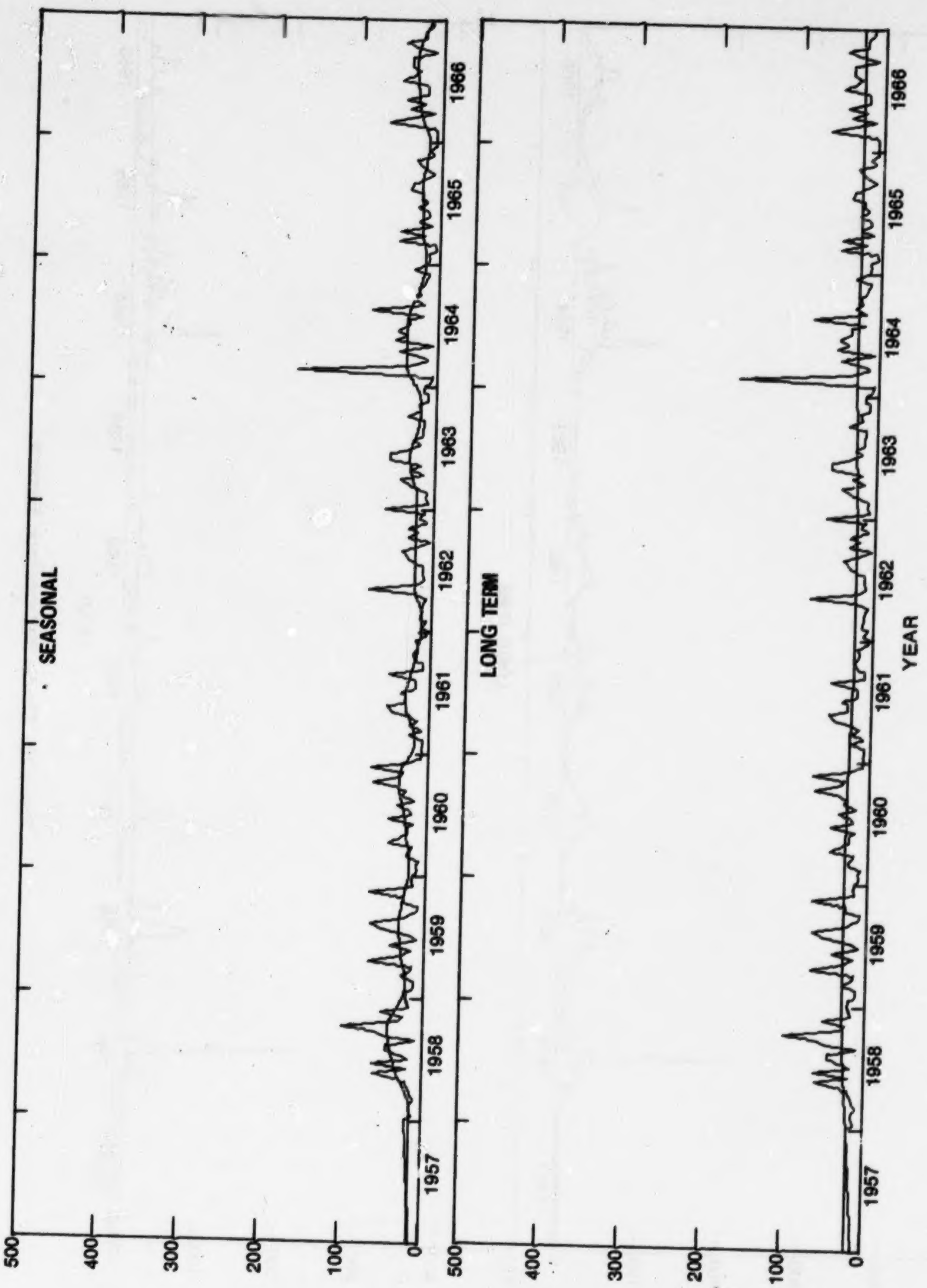

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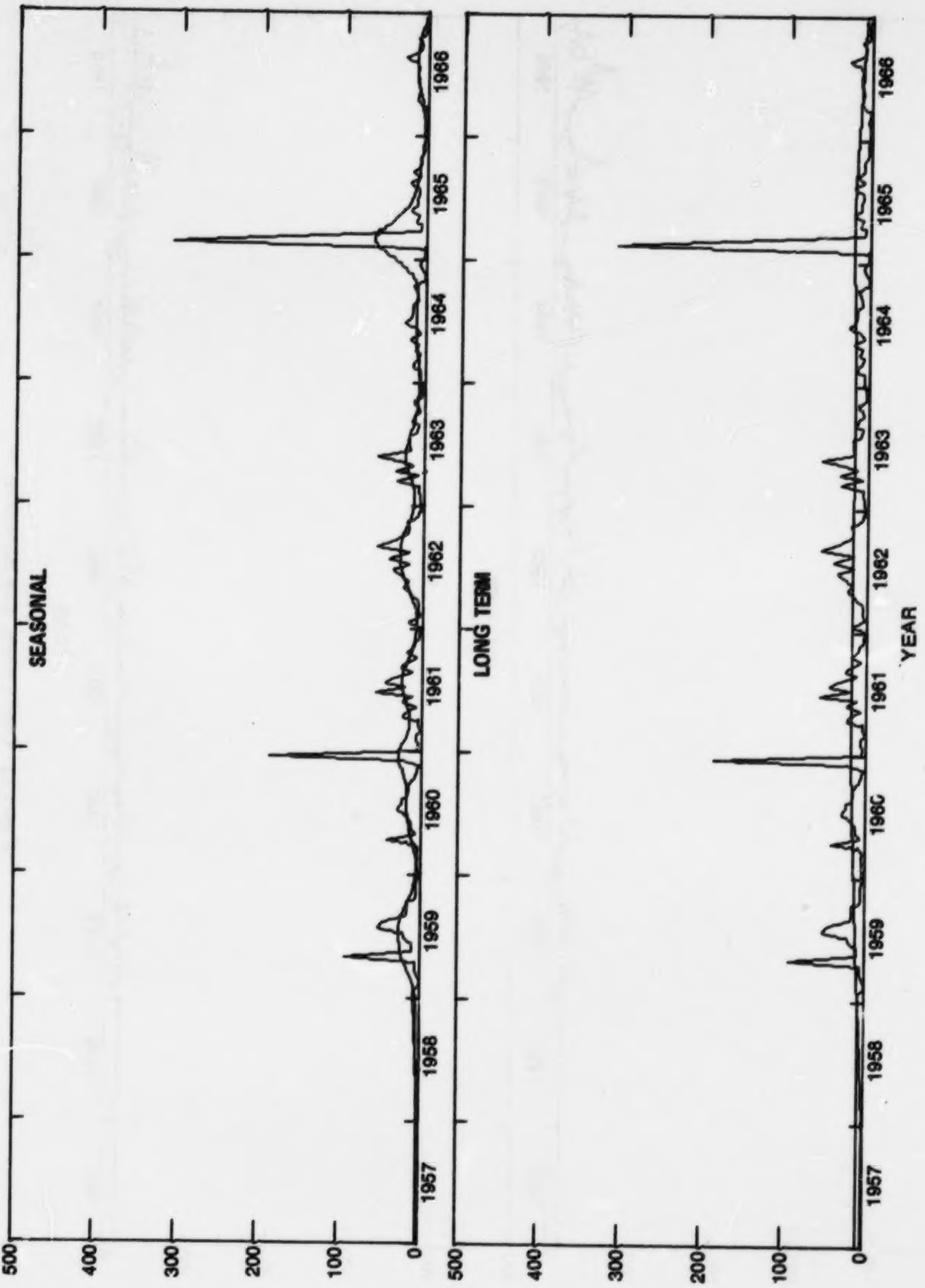

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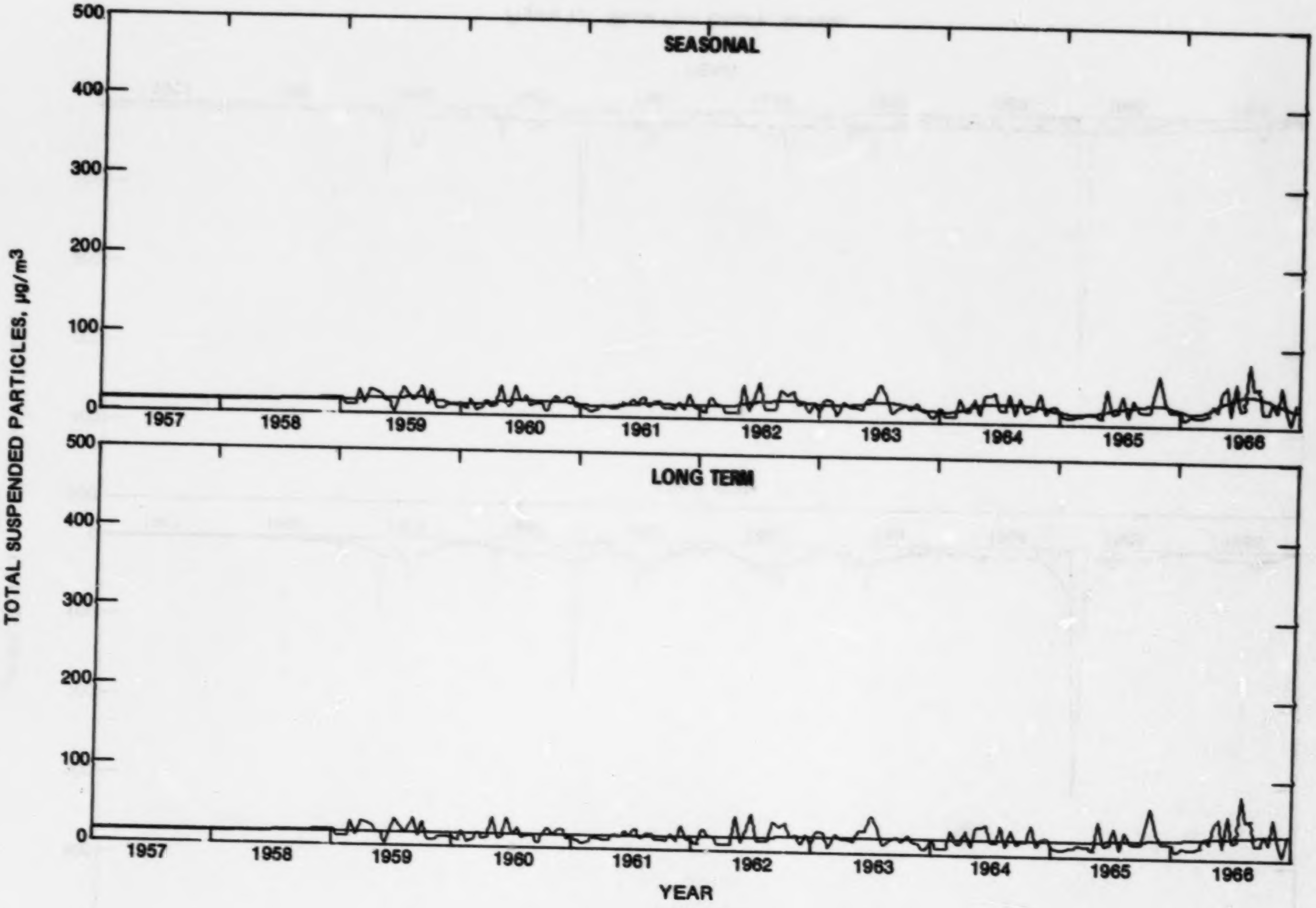

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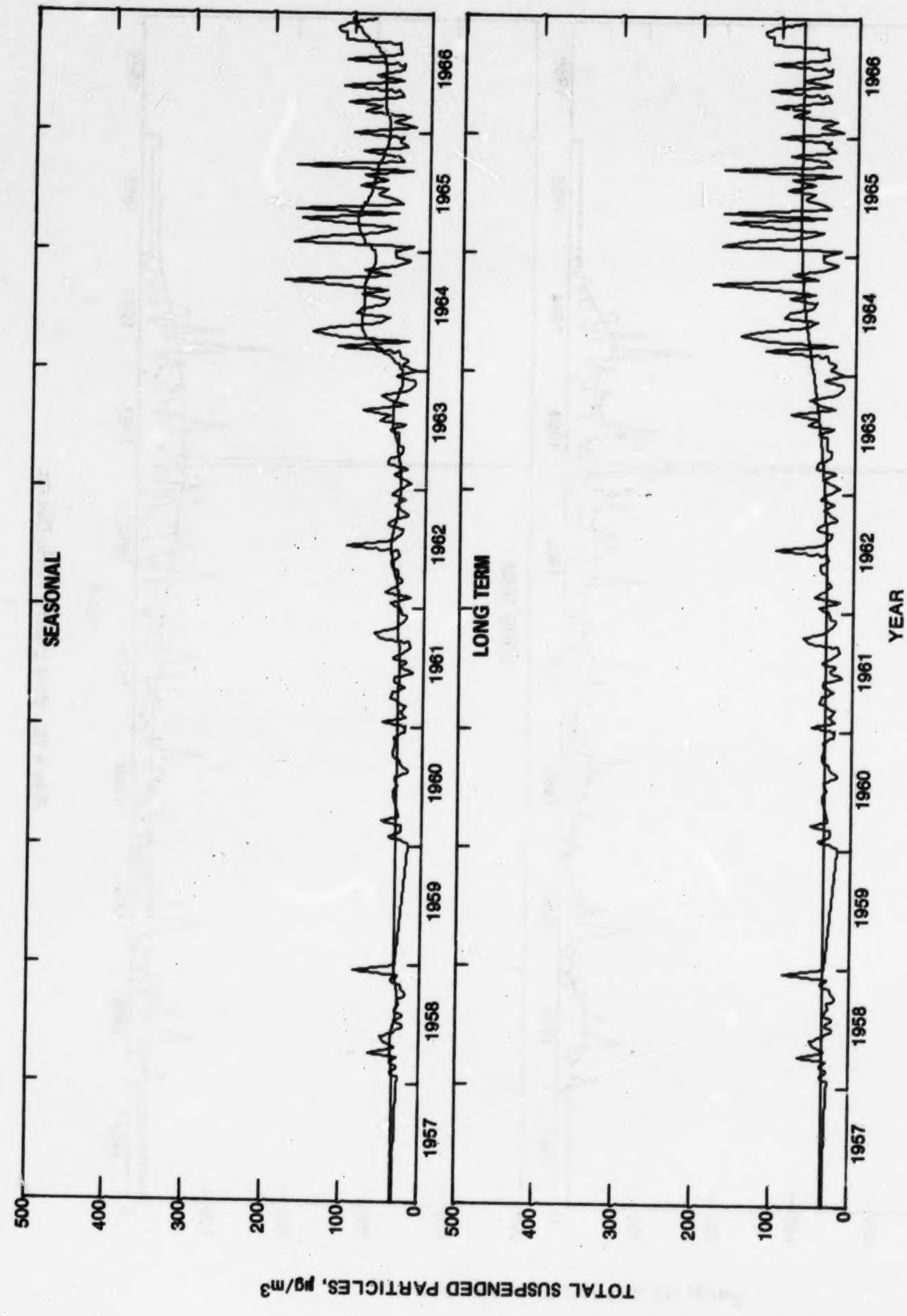
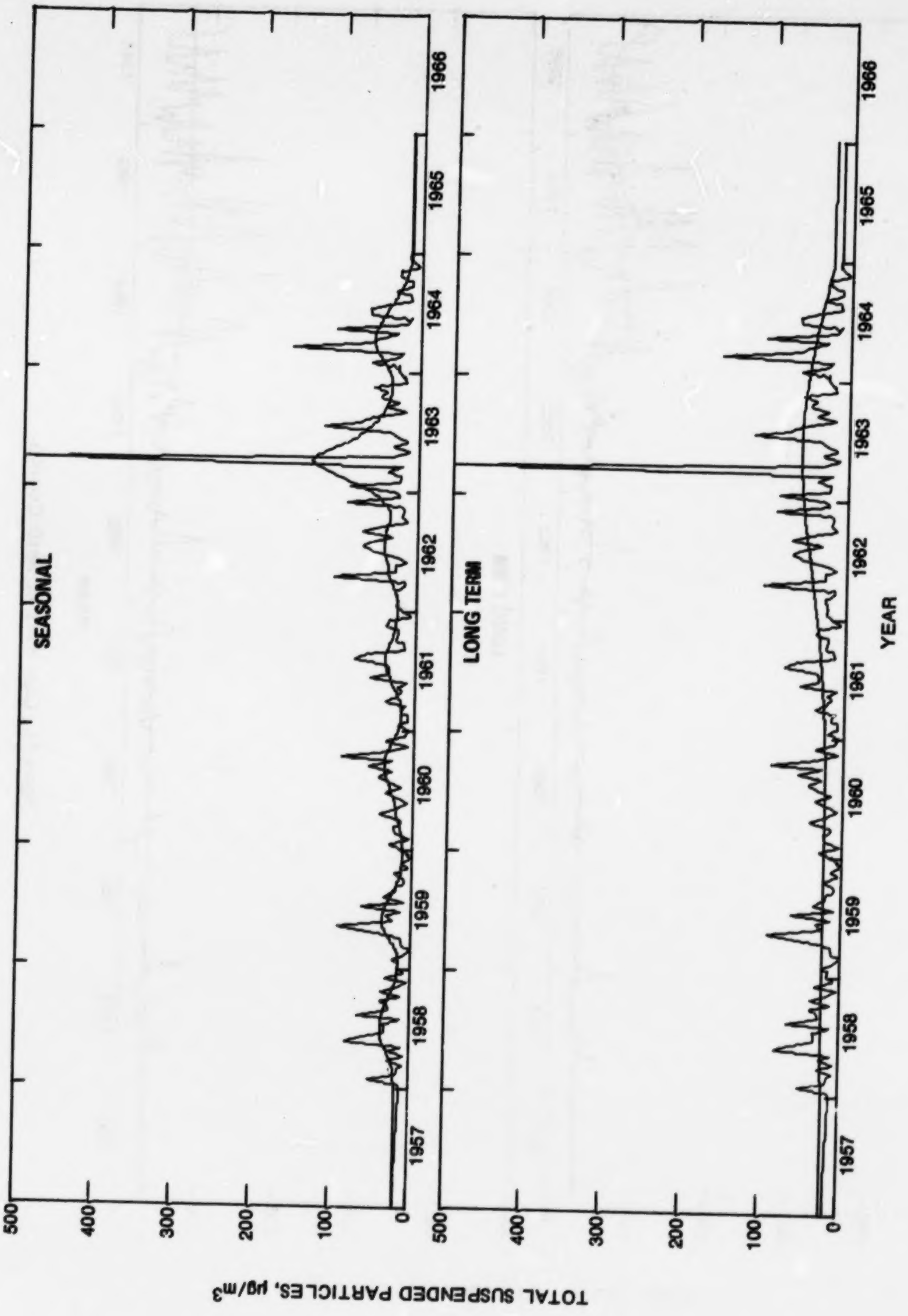


Figure 74. Cape Hatteras, North Carolina.



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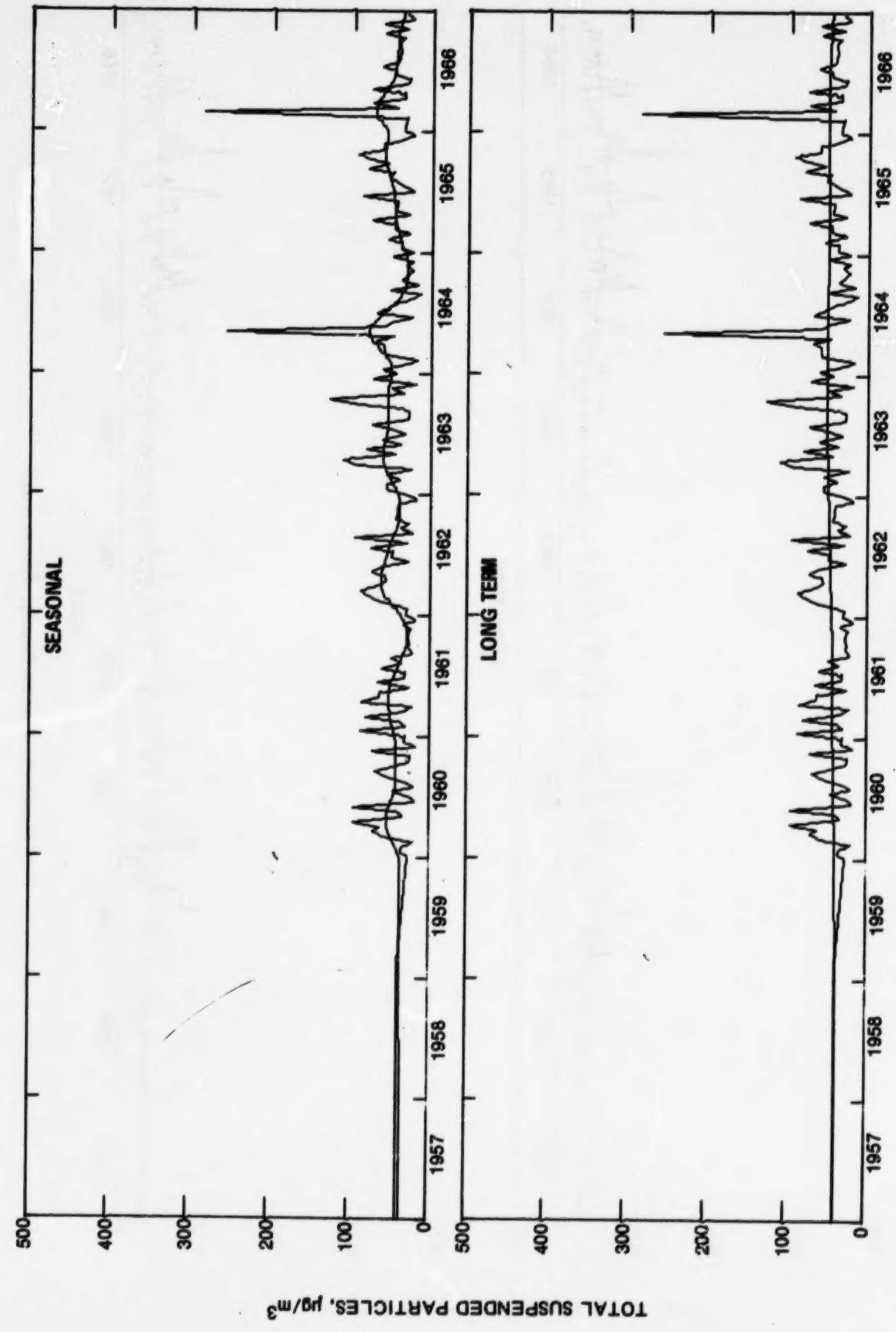

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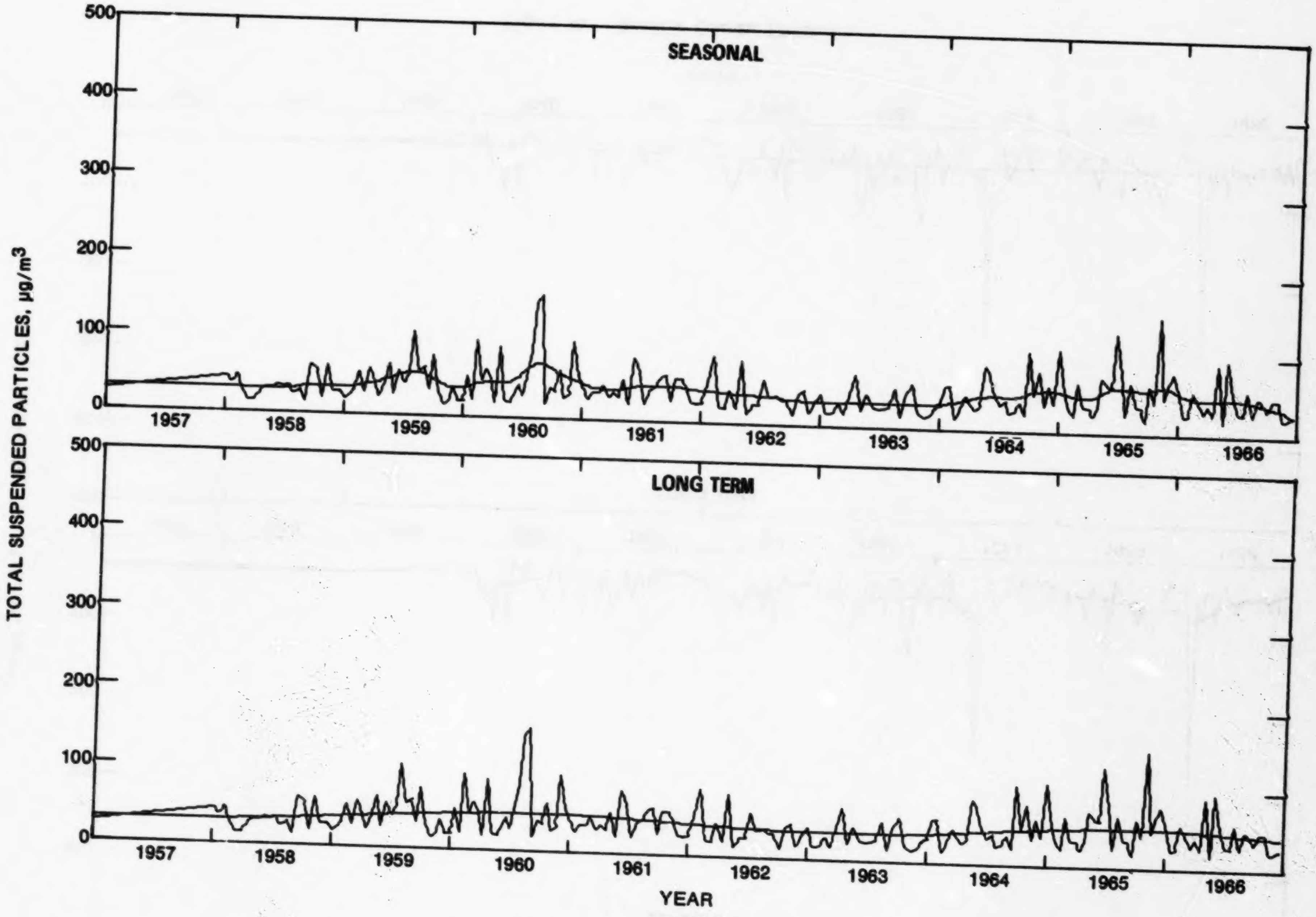

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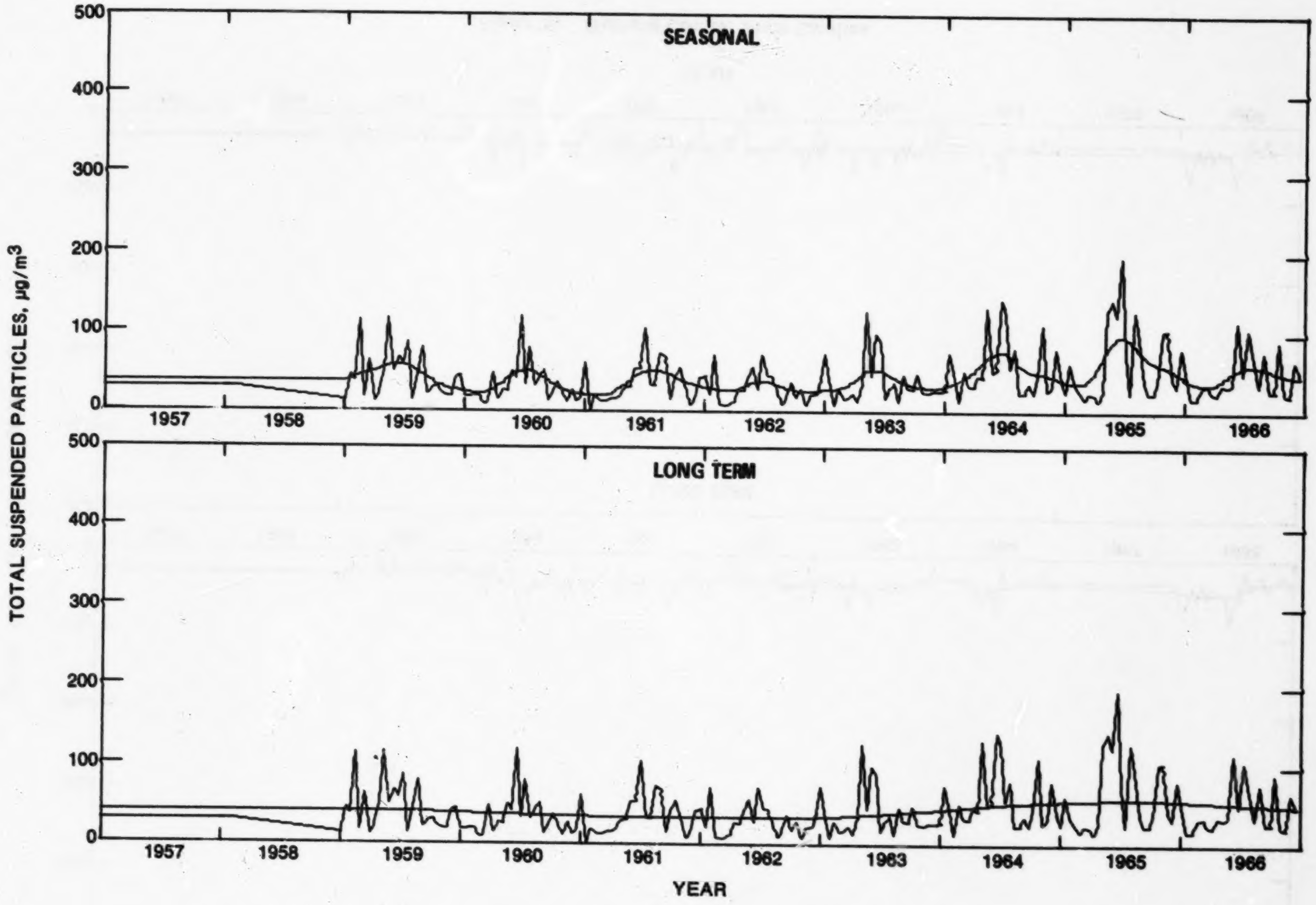

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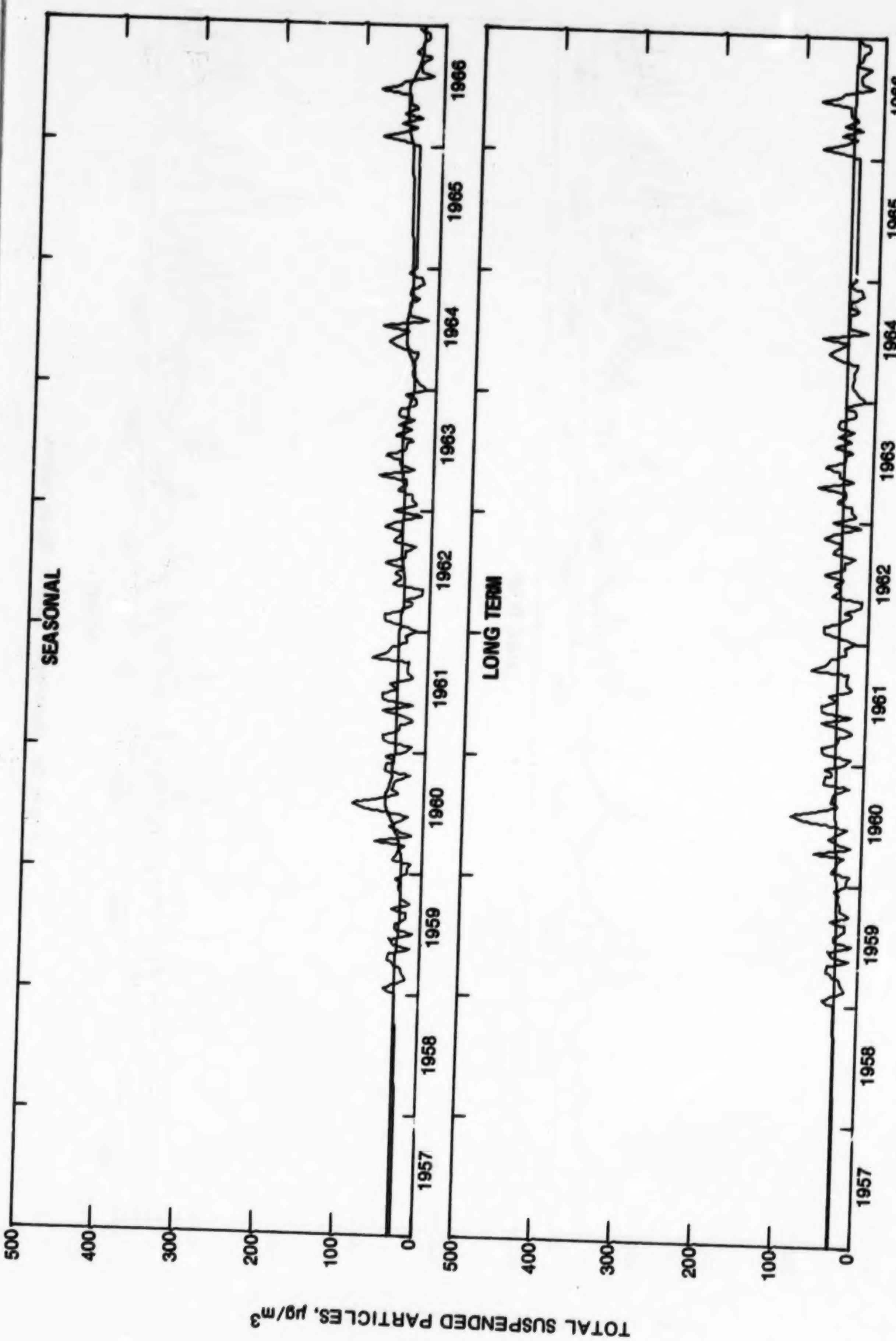

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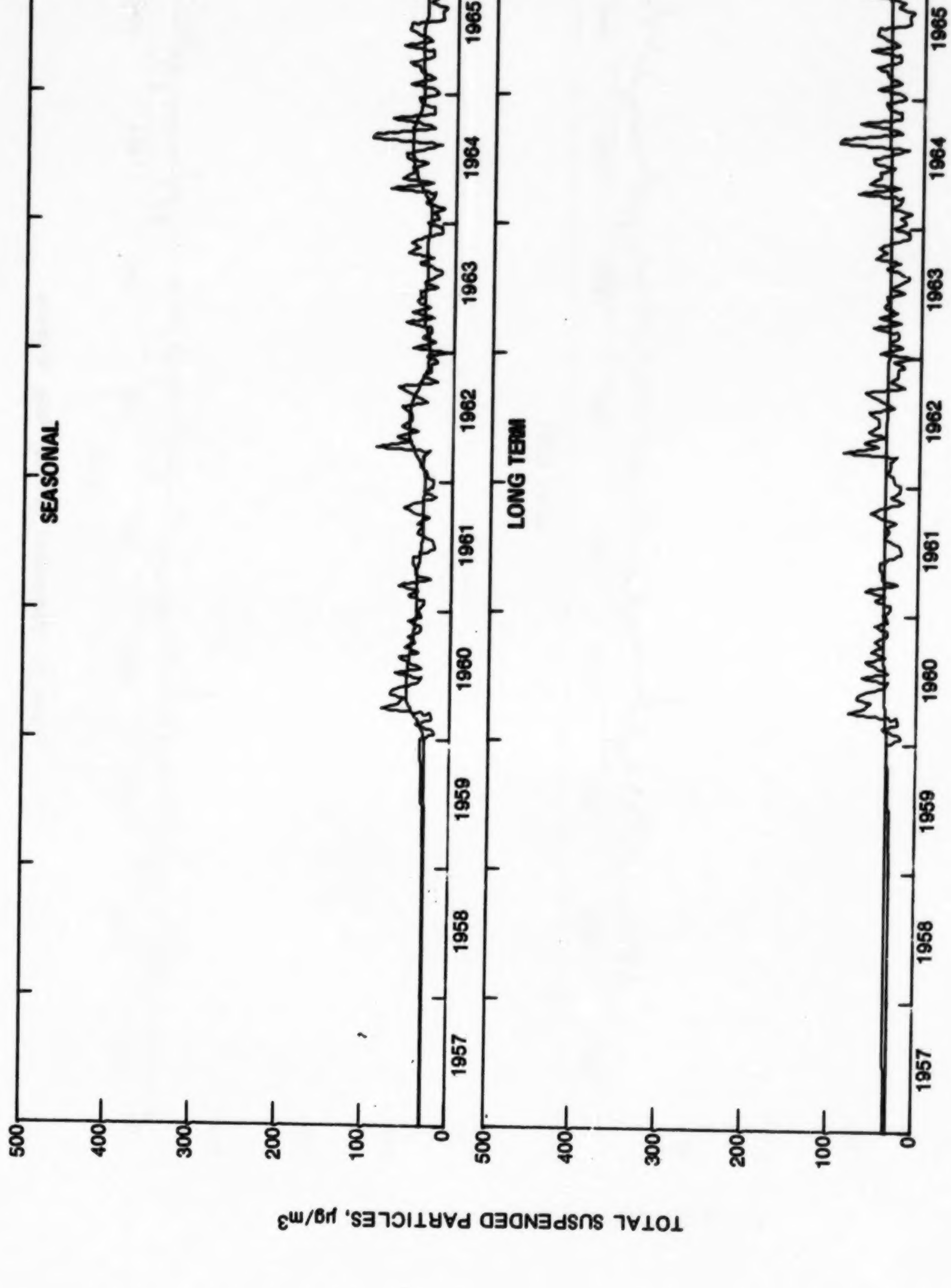

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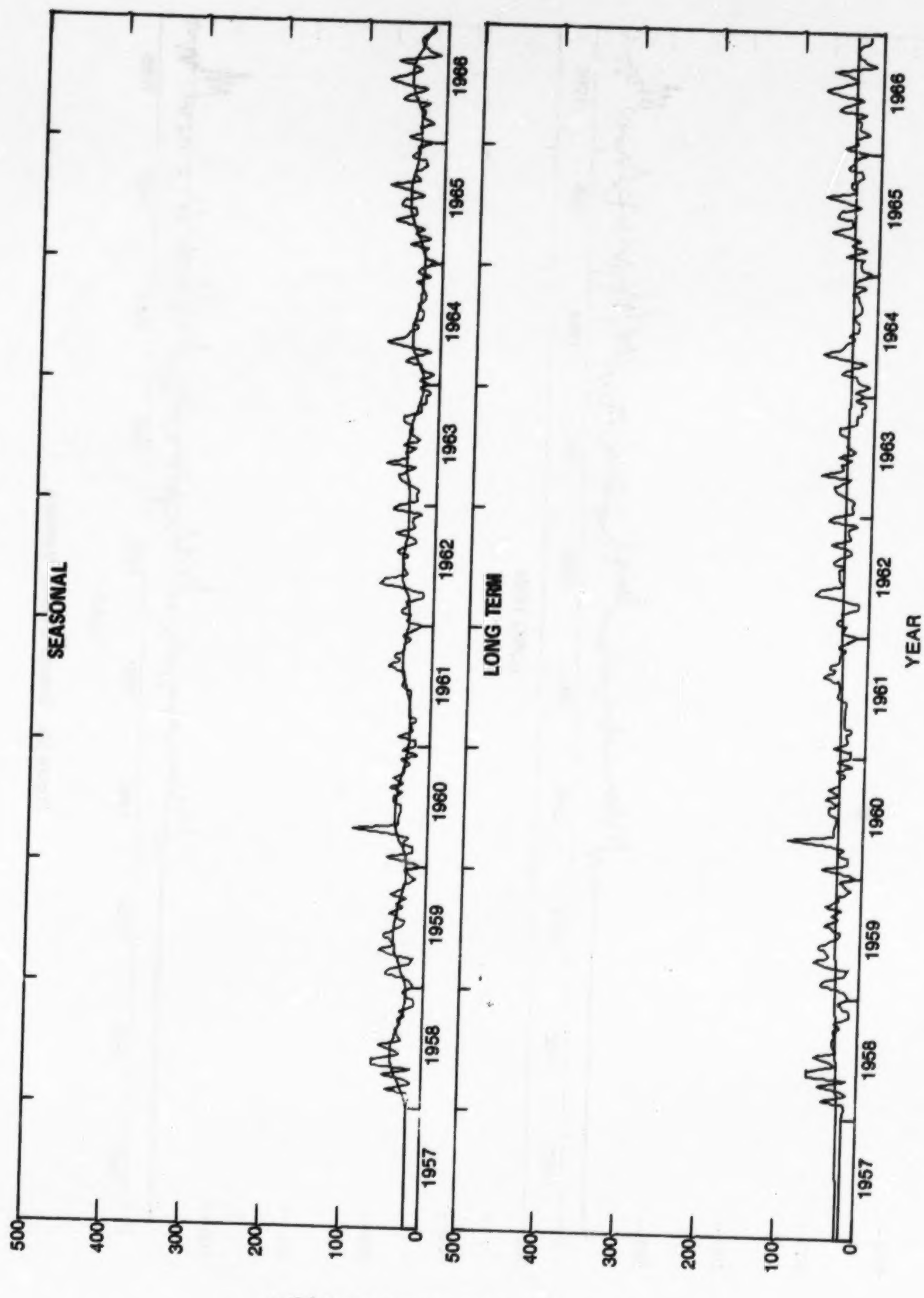

Figure 81. Shenandoah National Park, Virginia.

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16. Abstracts

The National Air Surveillance Networks (NASN) have collected samples of suspended particulate matter since 1957. The resulting suspended particulate data are graphically summarized by the application of Whittaker-Henderson Type A curve-smoothing formulas to 10 years of data. Data from 60 urban stations and 20 nonurban stations were studied by this technique, which brings out the underlying cyclical patterns and long-term trends in nationwide levels of suspended particulate matter. Seasonal patterns are evident for many urban and nonurban stations, and the seasonal characteristics of the two types of stations contrast sharply. Long-term trends are downward at many center-city urban sites, but are upward at some nonurban sites.

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